Energy ratings based on measured energy consumption: A practical approach for implementation of EPBD and identification of high-energy use buildings.

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ABSTRACT

Article 7 of the EU Energy Performance of Buildings Directive requires Member States to implement energy certification for buildings, and particularly for large public buildings, requires an energy certificate to be displayed in public. This paper outlines a simplified procedure for the certification of existing public buildings based on measured energy consumption, which is applicable even in countries where information on the building stock is not currently available. Energy consumption data collected for a number of buildings is used to develop energy benchmarks for typical and good practice energy performance. The rating procedure is based on a comparison between the energy consumption of each building and the derived benchmarks; a process that is illustrated in a sample of 88 Irish primary schools. The paper concludes with a discussion on the next steps to a more detailed measured rating procedure.

1 INTRODUCTION

EU Member States are in the process of implementing the Energy Performance of Buildings Directive (EPBD) (European Council 2002) which was transposed to national legislations in January 2006, a requirement of which is to provide buildings with energy certificates when constructed, rented, or sold.

Member States have or are in the process of developing tools for the certification of buildings. Devising certification tools that are robust and repeatable and at the same time easily applicable and cost-effective is a difficult task. This is particularly the case for non-domestic buildings, which comprise a full range of types, sizes and usages. A detailed knowledge of the energy performance of the building stock is often a pre-requisite for the development of appropriate tools. While some countries have a good tradition of calculating energy performance, conducting energy audits and processing energy performance data, other Member States are facing the situation of having to develop tools without previous knowledge of their building stock.

This paper presents a rating methodology that is easily applicable and with only outline knowledge of the building stock energy performance required. The methodology is based on the actual measured performance of buildings and is here applied to schools. A rating based on measured energy use is appropriate for public buildings as the EPBD requires them to place certificates in a prominent place clearly visible to the public and generally experience fewer sale or rent transactions than other non-domestic buildings.

From the range of public non-domestic building types this research targeted primary schools. Primary schools represent a reasonably homogeneous group with similar building size and construction types and also present similar occupancy profiles and types of usages. This makes them a suitable study group for the testing of a simplified rating approach based on measured energy usage.

Energy performance benchmarks for primary schools in Ireland did not exist at the time of this research. The data required to establish energy benchmarks was based on the size of the buildings and the annual energy use by each energy carrier. The required data was collected for primary schools by means of questionnaires. The most effective model of questionnaire proved to be one-page in length and with simple data entries that offered the respondents the possibility of inputting the annual energy use data in whatever measure they had available (energy costs, liters of oil, etc.). The questionnaire also allowed the number of pupils to be stated as an additional indication of the size of the building where the area was not known. Post-processing of the information was required to help complete the information and included assumptions to convert energy costs into energy usage and converting the number of pupils into a corresponding internal floor area based on average figures of pupils per square meter (available for approximately 50% of the schools). This normalization facilitated the derivation of benchmarks in terms of kWh/m^2.

For the purpose of this research, 88 Irish schools for which electricity and fossil fuel indicators were collected is considered as a representative sample of the Irish primary school building stock. Figure 1 shows the data for the 88 schools on a cumulative distribution.

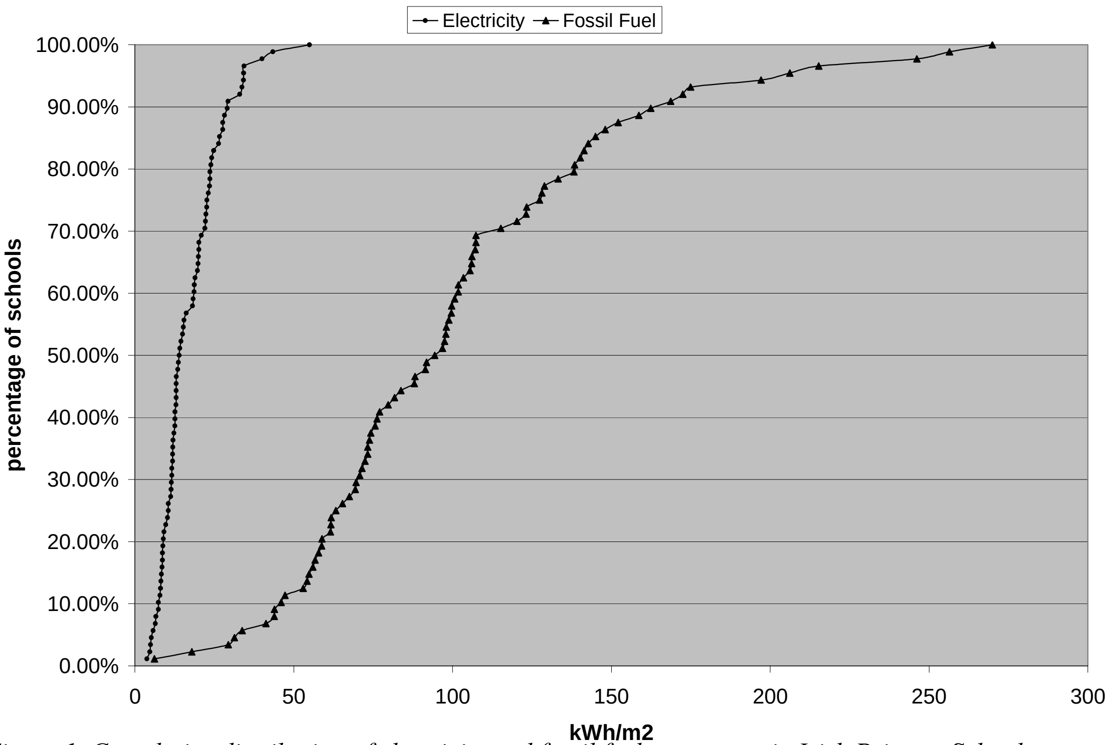

Figure 1. Cumulative distribution of electricity and fossil fuel energy use in Irish Primary School

Based on this distribution, the following definition of benchmarks was applied for the primary school building stock in the Republic of Ireland.

- Typical practice: The performance achieved by 50% of the building sample, which is the median of the distribution.
- Good Practice: The performance achieved by the best 25% of the schools from the building sample, which is the lower quartile of our distribution.

The results from this exercise can then be compared with other existing international benchmarks with similar climate and construction characteristics (Jones at al. 2000, The Carbon Trust 2005).

Table 1. Energy performance benchmarks for annual energy use at primary schools (kWh/m²)

Region	Electricity		Fossil Fuel	
	Typical	Good Practice	Typical	Good Practice
UK	34	25	157	110
Northern Ireland	18	12	119	91
Republic of Ireland*	14	10	96	65

* Developed from our building sample of 88 primary schools

From this comparison it can be observed that the developed benchmarks in the Republic of Ireland are considerably lower than the equivalent in Northern Ireland and in the UK. Possible explanations for those differences, which justify further research, might be variations in occupancy hours and holidays, quality of the construction and systems, the indoor environmental conditions, and differences on the climates.

3 'BUILDING ENERGY EFFICIENCY' AND 'MEASURED EMISSIONS' RATINGS

The draft European standard prEN15217: 2005: Energy performance of buildings- Assessment of energy use and definition of energy ratings (CEN 2005) establishes a grading method for building energy performance, sub-divided into seven grades as described in Table 2.

Table 2. Grades classification according to prEN 15217:2005

Class A	$EP < 0.5\ R_r$
Class B	$0.5\ R_r \leq EP \leq R_r$
Class C	$R_r \leq EP \leq 0.5(R_r+R_s)$
Class D	$0.5(R_r+R_s) \leq EP \leq R_s$
Class E	$R_s \leq EP \leq 1.25R_s$
Class F	$1.25R_s \leq EP \leq 1.5R_s$
Class G	$1.5R_s \leq EP$

EP is the energy performance of the building to be graded. The reference values R_r and R_s are defined at national or regional level. For this grading exercise, the following were used:

- R_r corresponds to a 'Good Practice' benchmark.
- R_s corresponds to a 'Typical Practice' benchmark.

With this classification and associated reference values, the rating of the primary school buildings energy performance is now possible. For this exercise two different types of ratings have been defined: the Building Energy Efficiency Rating and the Measured Emissions Rating

3.1 *Building Energy Efficiency Rating*

This rating is based on the separate electricity and fossil fuel energy use and their combined weighted overall energy use. A weighting factor of 2.5 has been applied to the electricity supply, based on the relative thermodynamic efficiency of energy delivered to the buildings, as a simplified approach to represent common practice on energy conversion. Table 3 shows an example of energy efficiency grades for a selection of schools analysed.

Table 3. Energy Efficiency Ratings for sample Irish Primary Schools

School ID	Energy Use (kWh/m^2)		Energy Efficiency Grade		
	Electricity	Fossil Fuel	Electrical	Thermal	Overall Building
PR_17	8.4	54.2	B	B	B
PR_21	4.7	73.3	A	C	B
PR_30	10.3	33.8	B	B	B
PR_88	29.1	6.1	G	A	B
PR_38	18.9	61.8	E	B	C
PR_39	13.5	73.3	D	C	C
PR_12	8.8	140.2	B	E	E
PR_40	34.2	54.8	G	B	E
PR_45	14.5	128.9	E	E	E

The four schools at the top of the table present an overall building energy efficiency grade B, which suggests that the schools are relatively energy efficient and perform better than 'Good Practice' or, more precisely, that they are within 25% of most energy efficient schools. The two samples in the middle, with an overall grading of C, perform in between 'Good Practice' and 'Typical Practice'. The three sample schools at the bottom, with an overall building energy efficiency grade of E, perform worse than the 'Typical Practice'.

We can also observe that thermal and electrical efficiency differs in cases from the overall building efficiency. For example, school PR_40, with a relatively low total delivered energy consumption, has an overall grade E as it exhibits poor electrical efficiency (Grade G), which is weighted at 2.5 in the overall grade. This approach would allow us to quickly identify schools with poor overall efficiencies and suggest the issues to be considered in each particular school with a view to improving overall energy efficiency. (e.g. lighting controls where there is a bad electrical efficiency grade).

3.2 *Measured Emissions Rating*

This rating assesses the overall emissions from a particular building and is particularly useful for comparison with building regulations or other policies relevant to an assessment of the building's contribution to national CO_2 emissions.

For the calculation of the grades, carbon dioxide emission factors have been applied to the different fuels used by a particular building. For this exercise, emission factors of 0.198 kg CO_2 per kWh for natural gas, 0.264 kg CO_2 per kWh for oil and 0.651 kg CO_2 per kWh for electricity have been applied and are based on national figures (Sustainable Energy Ireland 2005).

For the conversion of the 'Typical Practice' and 'Good Practice' energy performance benchmarks into emissions benchmarks weighting factors must be defined. In this example, we use the same conversion factor for electricity from the national figures and the conversion factor of natural gas for fossil fuel. Because of this approach, schools that use any other fossil fuel than gas are likely to get a worse rating, as they will be compared with benchmarks calculated using the weighting factor of natural gas. This decision has been taken as an approach to demonstrate how ratings can encourage the use of cleaner fuels (e.g. gas instead of oil) as well as more efficient technologies.

Table 4 shows an example of two schools for which the measured emission grades have been calculated.

Table 4. Measured Emissions Ratings for two sample Irish Primary Schools

School ID	Energy Use (kWh/m^2)		Emissions (kg CO_2/m^2)		Measured Emissions Grade
	Electricity	Fossil Fuel	Electricity	Fossil Fuel	
PR_38	18.9	61.8	12.3	16.3	E
PR_39	13.5	73.3	8.8	14.5	C

School PR_38 used oil for space and water heating and PR_39 used natural gas. This factor, together with the higher relative use of electricity by PR_38, results in this school exhibiting greater emissions and being two grades above PR_39 for the measured emissions rating, despite having similar delivered energy use and the same overall building energy efficiency grades as was shown in Table 3.

4 APPLICATION OF THE RATINGS TO THE PRIMARY SCHOOL BUILDING STOCK

The two rating methods presented have been applied to the building stock sample represented by the 88 schools. Figure 2 shows the distribution of grades. For the energy efficiency ratings, 50% of the schools will have a grade between A and D, and 50% of the schools a grading between E and F as the limit between grades D and E as defined in pr15217:2005 (CEN 2005) is the median of the building stock.

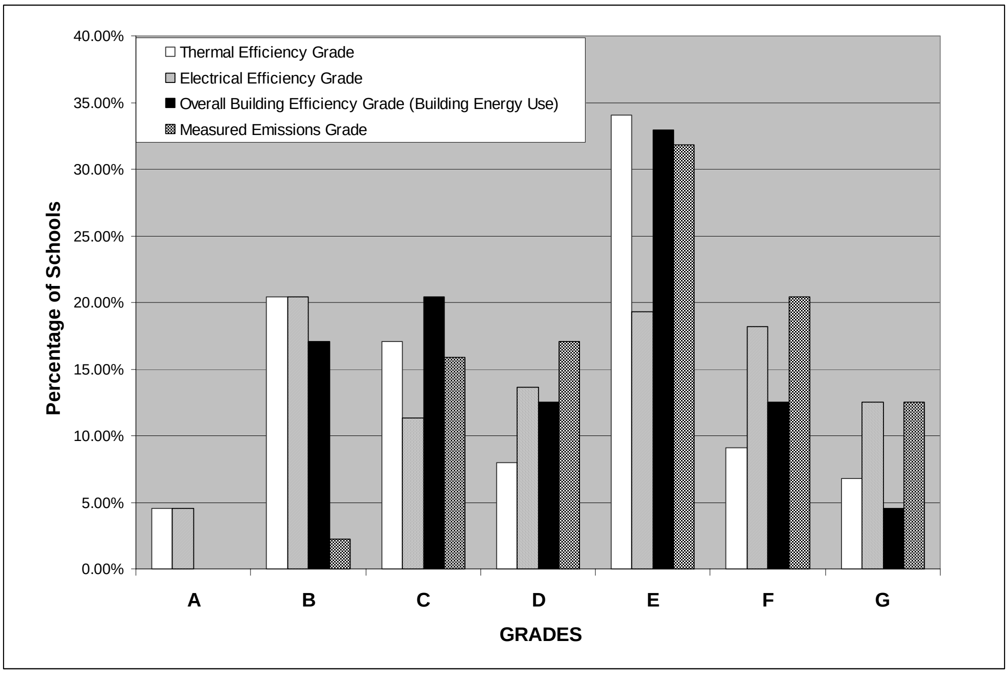

Figure 2. Distribution of Grades for the sample of 88 schools.

For the measured emissions grade, we can observe in the figure the influence of the approach of promoting cleaner fuels by using the weighting factor of natural gas for the fossil fuel benchmark. The measured emission grade is substantially worse than the overall building energy efficiency grade; only 35% having a grade between A and D and the other 65% of the schools in the building stock having the poorer rate of E, F or G. This result is due to the fact that, at present, most of the schools from the building stock use oil as their main heating source, which has more associated emissions than natural gas.

5 FURTHER DEVELOPMENTS OF MEASURED RATINGS.

The simple methodology presented in this paper supports the identification of high energy users and high polluting buildings in a quick and cost effective way. It is expected that buildings which are awarded a poor rating or with a lower rating than expected might undertake a more detailed analysis. For further analysis, the methodology can be fine-tuned and expanded to account for possible particularities of a building. The EPLABEL project (2007) has developed a tool for certification including elements that facilitate this further analysis. The first refinement is to allow the identification of special energy uses within the buildings (such as car park lighting, server rooms, etc), which could have distorted the rating because these end uses are not included in the benchmarks. This quantification of a special energy use would help to further refine the comparison between a specific building and the benchmarks for its building type. Figure 3 illustrates part of the measured energy being identified as a special energy use that is deducted before a comparison is made with the benchmarks.

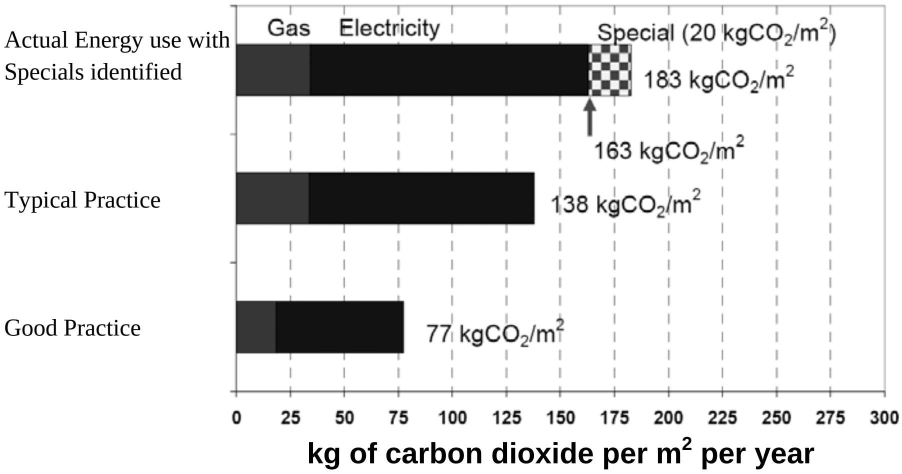

Figure 3. Allowing for identification of energy uses before comparison with benchmarks.

A further step also explored by the EPLABEL project (2007) is the
rating based on a comparison of a building's performance with customized benchmarks which are related to the specific activity and occupancy hours of the building in particular.

Figure 4 shows an example of the use of customized benchmarks for an office building. The measured energy use by the actual building, split between the fossil fuel and electricity is compared with typical and good practice benchmarks for a building of the same type, occupation and activities as the actual building.

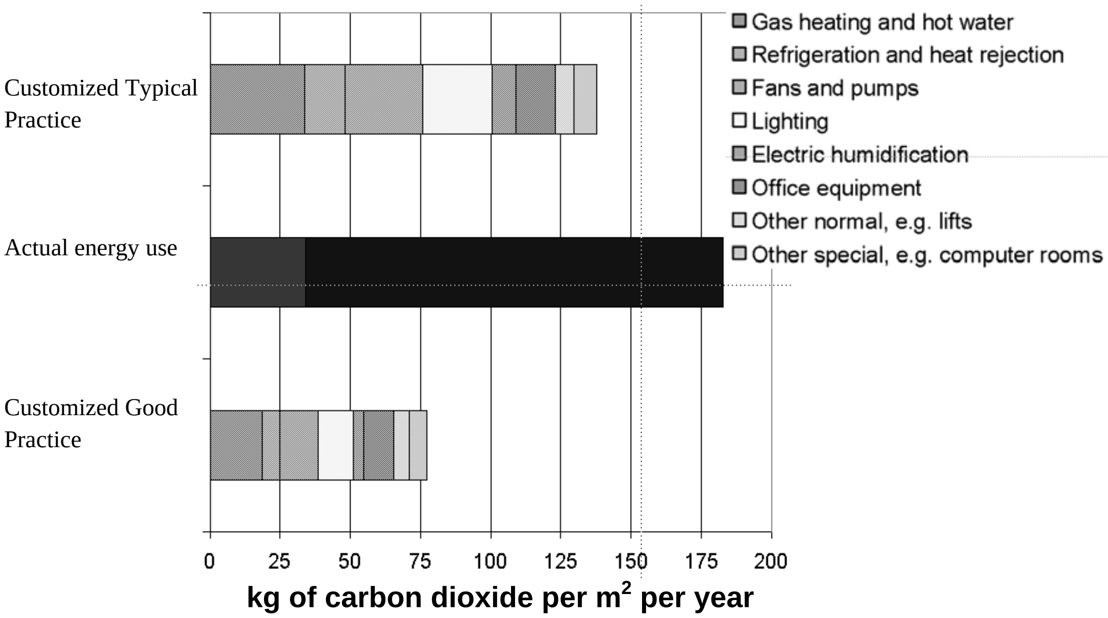

Figure 4. Comparison with customized benchmarks for activities and occupancy hours of the specific building, segregated in different systems.

In the situation where sub-metering is installed, it is possible to compare a measured individual energy end use with its respective benchmark, enabling different efficiency ratings to be applied to each energy end-use (heating, cooling, fans, lighting, etc).

It is also possible to extend this approach to component benchmarks, often expressed in W/m^2 of installed capacity (e.g. for heating, cooling, fans, pumps, lighting and office equipment), and/or as efficiency indicators, for example W/(litre per second) for mechanical ventilation systems and W/m^2 per 100 lux for lighting.

Customised benchmarks have two further uses:

- Simply by knowing the specific activities and intensity of occupation of a building one can generate the customised benchmark. Because it is tailored to a specific building, it can be used to estimate the relative scale of each energy end-use without any expert input: this is potentially powerful as it allows non-technical people to get more information.
- In a further step, the relative size of each energy end use in the benchmark can be applied to the measured energy use of the actual building, affording a first estimate of the actual energy end use breakdown. This breakdown can be refined by any further knowledge about the building, for example if there is sub-metering available or a robust estimate for one or more energy end uses as the lighting can be made.

Once the analysis has reached the stage of examining the actual energy end use breakdown, the assessor has moved towards identifying potential energy saving measures for the different end-uses. This approach would be particularly robust when sub-metering has been implemented in one or more of the major energy uses in a particular building.

6 DISCUSSION AND CONCLUSIONS

The advantages or disadvantages of measured versus calculated ratings, which have been extensively discussed in various European Forums, CEN committees and publications (Visier 2006) are not discussed in this paper. Instead, a practical methodology to produce energy ratings for use in existing public buildings based on measured energy consumption has been presented.

This simplified methodology aims to serve as a first step towards certification which is cost-effective, offers a quick implementation and would allow the identification of the worst performing buildings, which can then be encouraged to implement measures for improvement of the energy performance.

A sample representing the Irish building stock of primary schools is used as a practical example on how this measured rating could be implemented with very little resources. The method allows the identification of both buildings with high-energy use and buildings with high associated CO_2 emissions, by using the ‘energy efficiency’ and ‘measured emissions’ ratings. Each building can be provided with suggested priorities for improvement measures, either suggesting an improvement in thermal or electrical efficiency, the use of a fuel source with lower associated emissions (as natural gas or indeed renewable energy resources) or improving both factors.

Further refinement and fine-tuning of this measured rating approach has also been discussed, proposing customized benchmarking, which together with energy sub-metering could ultimately lead to a better understanding of the energy performance of the building stock and to identification of energy saving measures.

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REFERENCES

European Council 2002, Directive 2002/91/EC of the European Parliament and of the Council of 16th December 2002 on the energy performance of buildings.

EPLABEL 2007, A programme to deliver energy certificates based on measured energy consumption for display in Public buildings across Europe within a harmonising framework, *SAVE project supported by Intelligent Energy Europe, project website www.eplabel.org*

The Carbon Trust 2005, GPG343 Good Practice Guide, Saving Energy –A whole school approach

Jones, P.G. et al. 2000, Energy Benchmarks for public sector buildings in Northern Ireland, *Proceedings of CIBSE National Conference, Dublin*

CEN 2005, prEN 15217:2005, Energy performance of buildings-Methods for expressing energy performance and for energy certification of buildings

Visier 2006, Energy performance certification procedures, present status, *Information Paper P03, available for download at www.buildingsplatform.org*

Achieving Sustainable Infrastructure in Washington DC

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ABSTRACT: This paper provides details of the South Capitol Street project, a case study in urban sustainability. The planning and design process for the project was geared to achieving sustainable infrastructure and involved regular meetings of concerned agencies, selection of multidisciplinary consultant teams, regular briefings of politicians at the municipal and federal levels, and comprehensive public engagement. Major thesis of the paper, demonstrated in the case study, is that early collaboration between planners, designers, and engineers, with a mix of disciplines, and steady coordination with political interests, is crucial to urban sustainability. Washington DC, although the capitol of the United States, has been long divided by out-dated infrastructure planned and built at a time when the explicit goal was to clear out blight. Little thought was given to neighborhoods marginalized in the wake of such building. In the new millennium the southeast and southwest quadrants of the city are poised to be redeveloped as thriving urban nodes, and are among the last few places where major redevelopment can occur. However, the existing transportation infrastructure is deteriorated, performs poorly, fails to provide logical connections, and fences off prime developable parcels. In addition, this infrastructure is a barrier to access to the city's unique environmental asset, the Anacostia River. As one of the top ten polluted waters in the United States, it must daily absorb untreated urban pollution and runoff from roads and development in its watershed. It is in need of immediate attention.
The Anacostia Waterfront Initiative (AWI) is a unique partnership of federal and local agencies and is a significant revitalization effort for Washington DC. The AWI Framework Plan laid out specific ways that the corridor could be revitalized, including sustainable infrastructure. Improving the health of the river, rebuilding the landscape, and creating vibrant, sustainable communities will contribute to economic development and environmental quality that will be enjoyed by all of the city's residents. South Capitol Street project is underway and part of the AWI. The award-winning South Capitol Street project was planned, designed and will be constructed using several sustainability principles. As a piece of sustainable transportation infrastructure it will address the new context for the corridor while meeting the triple bottom line. Among other innovations, the facilities are designed to treat stormwater runoff onsite and low-impact design features are integrated into the streetscape (environmental). The District Department of Transportation has developed new standards and specifications for the AWI area that include permeable pavers, planting zones, solar-powered lights, and maintenance practices that improve environmental quality. The timing of the infrastructure improvements is carefully coordinated with developers to ensure minimum disruption to the completed facilities by future development and to maximize service to new development (financial). In addition to environmental benefits to the community, project includes training and outreach centers in the project neighborhood (community).

1 PROJECT CONTEXT

1.1 *Anacostia Waterfront Initiative*

The Anacostia Waterfront Initiative (AWI) in 2000 brought renewed attention to the land use and environmental character of the southeast and southwest quadrants of Washington DC. The Anacostia River, one of the tenth most polluted urban rivers in the United States, flows through the southeast portion of the District of Columbia This planning effort was a major partnership between federal and District of Columbia agencies to develop a clear vision for the Anacostia Waterfront. The partnership of agencies, all of which owned or controlled land along the waterfront, signed a Memorandum of Understanding that guaranteed their participation and cooperation in the planning effort. The District of Columbia Office of Planning (OP) created the Anacostia Waterfront Initiative Framework Plan in November of 2003. The plan identified major themes to guide development and revitalization efforts for the Anacostia waterfront area. The five themes of the Framework Plan are: a cleaner river, strong waterfront neighborhoods, new and revitalized waterfront parks, and vibrant cultural attractions.

1.2 *South Capitol Street Case Study*

South Capitol Street is one corridor in AWI. Details about its planning history are useful background to how parts of the project are being sustainably constructed. The case study also demonstrates some critical components of urban sustainability in addition to how early coordination is necessary for later sustainable construction techniques to be implemented.

1.2.1 *History of South Capitol Street*

South Capitol Street was a primary corridor in L'Enfant's 1791 Plan for the City of Washington and has always been envisioned as a symbolic gateway to the city and its Monumental Core. South Capitol Street connects downtown Washington to neighborhoods in the southeast and southwest quadrants of the District of Columbia and Prince George's County, Maryland. The L'Enfant plan for the City of Washington positioned the United States Capitol on Jenkins Hill, then the highest point in the city. The US Capitol was the focal point of the L'Enfant Plan. Three 130-foot wide boulevards, North, South and East Capitol Streets, radiated from it and divided the city into quadrants. Initially, South Capitol Street was the most prominent because it served as the primary entrance to the city for those arriving by boat, the most common means of transport in the 18th and 19th Century. South Capitol Street soon became the backbone of the city's industrial section. Ship building companies and other manufacturing enterprises dominated area and the waterfront, many of which supported the Washington Navy Yard, the city's largest employer during the 19th-century.

South Capitol Street as it is today, was designed and built in the 1950s, conceived as part of a network of expressways that would lace the Washington Metropolitan region. This included widening the right of way at M Street to create a grade-separated intersection, and building a viaduct which would carry motorists quickly through Southeast and Southwest. These areas were considered blighted and areas to travel through, rather than destinations. South Capitol Street then connected to the new Suitland Parkway, completed in 1944. Connections were also built to I-295 in the 1950s. In the late 1960s, the SE-SW Freeway, which bisects South Capitol Street, was completed. In the 1970s, an additional lane was added to the Frederick Douglass Memorial Bridge. This was the last time major physical alterations were made to South Capitol Street.

Today, South Capitol Street lacks any characteristics of its historic function as a gateway and the street's present characteristics and conditions are not appropriate to its central place and important function. South Capitol Street is an urban freeway that has become a conduit for through traffic at the expense of serving the immediate needs of the residents and businesses in the corridor. The transportation infrastructure is unsafe, in deteriorating condition, and fails to provide necessary connections to community destinations for pedestrians, bicyclists, transit riders, or motorists.

1.2.2 *Changing Land Use*

The area surrounding South Capitol Street consists of a variety of land uses. West of the river, on the east side of South Capitol Street, land uses are predominantly commercial and consist of gas stations, fast food restaurants and vacant lots. Properties to the west of South Capitol Street consist of vacant and underutilized industrial properties, with a few active industrial sites. East of the river, the land use is predominantly federal (parkland and military facilities) with some residential along Firth Sterling.

Despite the inadequacies of the transportation infrastructure in the corridor, new development is rapidly transforming former industrial and military uses into thriving mixed use communities and employment centers. This public investment has stimulated private investment in new residential, office, and retail developments throughout the corridor. The economic development of the South Capitol Street Corridor and along the Anacostia River is part of a District of Columbia and regional effort to revitalize the waterfront and clean up the river. The vision for the Anacostia Waterfront is an area that will unite the city economically, physically, and socially as the center of 21st century Washington and a cornerstone of the National Capital Region. South Capitol Street's transportation infrastructure must support and enhance this new vision of the Anacostia Waterfront.

1.3 *Planning Background of the Project*

As mentioned in the introduction, planning efforts have been underway for more than a decade to transform South Capitol Street into an urban boulevard that responds to and serves its local context while restoring its function as a symbolic gateway. In 1997, the National Capital Planning Commission (NCPC) completed a framework plan, Extending the Legacy: Planning America's Capital for the 21st Century (NCPC 1997), that extended the Monumental Core to include South Capitol Street. In its plan, NCPC envisioned "South Capitol Street as a bustling mix of federal, local, and private uses. A major memorial or public building can be located on the important site where the street meets the river, and the new South Capitol Street can become a lively area of shops, restaurants, housing, offices, and open space." This work continued in the South Capitol Street Urban Design Study (NCPC 2003).

As defined in the *AWI Framework Plan*, the future of the Anacostia Waterfront will include a cleaner river, strong waterfront neighborhoods, new and revitalized waterfront parks, and vibrant cultural attractions, as well as better access both to and between these neighborhoods and destinations. In 2002, DDOT built upon the *AWI Framework Plan*, by undertaking a series of planning and engineering studies investigating and analyzing the Anacostia Waterfront's existing and future transportation patterns, needs, opportunities and constraints. The effort included *The South Capitol Gateway and Corridor Improvement Study* (Gateway Study), *South Capitol Gateway Corridor and Anacostia Access Studies*, a tunnel study to determine the feasibility to replace the Southeast-Southwest (SE-SW) Freeway, the South Capitol Street Bridge Design Workshop, and the *Frederick Douglass Memorial Bridge Alignment Study*.

The *Gateway Study* created a vision for transforming South Capitol Street from an unsightly freeway into a grand urban gateway. Performed at the direction of the United States Congress, the *Gateway Study* was "a study of methods to make improvements to promote commercial, recreational, and residential activities and to improve pedestrian and vehicular access on South Capitol Street and the Frederick Douglass Memorial Bridge." The *Gateway Study* proposed that South Capitol Street would become a gracious urban boulevard that would accommodate bicycles, pedestrians, and transit vehicles, as well as automobiles and commerce. The study also recommended constructing a new Frederick Douglass Memorial Bridge on a southern alignment and at a more urban scale than the present bridge. The transportation improvements would also improve access to new activity centers and support economic development and revitalization of the Anacostia Waterfront.

The recommendations from the Gateway Study were examined in more detail in the *South Capitol Gateway Corridor and Anacostia Access Studies*. As the project developed momentum, the *Anacostia Crossings Project Memorandum of Understanding* (2004) clarified the federal and local partnership. As explained in the document, the USDOT would commit technical resources to expedite environmental and project development phases, including streamlining assistance. At the same time, the District of Columbia would create, through ongoing communication and collaboration, a climate among local interests and constituencies that would serve project advancement.

The next effort in project history, and one that worked in parallel to the environmental planning, was the *Frederick Douglass Memorial Bridge Alignment Study* ([*Alignment Study*] DDOT 2007). The *Alignment Study* developed technical constraints for the bridge alignment and bridge types. The work accomplished by the *Gateway Study* (DDOT 2003), the *South Capitol Gateway Corridor and Anacostia Access Studies* (DDOT 2004), and the *Frederick Douglass Memorial Bridge Alignment Study* (DDOT 2006) as well as the positive reactions of the stakeholders and sponsors to these efforts, established the purpose and need for the South Capitol Street project.

1.4 *Why is it "urban sustainability"*

People have historically and will continue to gravitate to cities. Wise civic leaders recognize they must improve the infrastructure, social and physical, to attract new residents and inspire the private sector with targeted public realm investments. Wise civic leaders also recognize that they have limited funds and resources to provide a host of civic goods. Urban sustainability is the wise use of civic resources to create dynamic, healthy urban environments that do not haphazardly rob the future of resources. Urban sustainability means that within the context of dense urban environments, the triple bottom line is met: people, environment, and money. Planning, designing and building infrastructure that responds to the future context for city districts is an important step in urban sustainability.

South Capitol Street will be rebuilt as an urban boulevard, figure below, with signalized at-grade intersections, a new bridge that provides safe and pleasant pedestrian and bicycle connections across the river, a new interchange from a parkway to a redeveloping neighborhood, and provides missing regional transportation movements which are currently inadequately provided by local streets, to the detriment of those neighborhoods. Creating sustainable transportation was an important guiding principle throughout the South Capitol Street project development process. Instead of just replacing in kind, thoughtful planners and engineers considered how to best serve the future population with a transportation facility that meets the needs of multiple modes.

New at grade intersections allow future residents and visitors to cross a gracious tree-lined street to access new retail, residential, recreational, and commercial uses. An integrated pedestrian network will improve pedestrian mobility throughout the area and create safe attractive links to transit nodes. The pedestrian network will also provide access to the range of services, jobs and recreational activities planned and in construction in the area. Improved conditions are planned for cyclists, allowing them to cross the river more safely, and connecting them to a planned 16-mile riverwalk trail. East of the river, realigning the bridge will free parkland and wetlands and provide a more marketable consolidated parcel for development. Pedestrian and bicycle networks will allow residents to access the riverfront recreational opportunities as well as new services and jobs.

2 EARLY COORDINATION: POLICY BASIS FOR SUSTAINABLE CONSTRUCTION

The federal and local land owners along the Anacostia River discussed how they could develop a vision to transform the waterfront. Washington had grown along the Potomac, however, the Anacostia riverfront had parks, which were hard for residents in neighborhoods next to them to access, and were not well-maintained. Residents considered these parks jewels for their neighborhoods, but difficult to access, and in need of improvement. It was clear that the existing infrastructure along the Anacostia River failed to serve current needs, and was entirely inadequate for the future to come. At the local and federal level, it was recognized that transportation infrastructure is an expensive public investment, it was treated as a trememdous public asset that should to be strategically used. This infrastructure, would be built to respond to the new context of the area, and would become the spine of the AWI redevelopment. The District Department of Transportation (DDOT) was an early partner in the AWI effort.

DDOT stepped in to coordinate the infrastructure side, and based on experience in other cities, recognized that the strong political will and partnership needed to continue. DDOT began hosting interagency coordination meetings which would continue to bring together all of the concerned parties to discuss the planning and design of specific infrastructure projects. These monthly meetings were forums for project details to be discussed and criticized and served as a regular conduit for project coordination and discussion. In stead of each agency operating in a vacuum, or a silo, at the interagency meetings they met face to face with colleagues, voiced concerns, set up meetings, discussed criticisms, and received advance notice of projects. DDOT organized and ran these meetings, demonstrating their leadership regarding the major transportation facilities that were being planned.

For projects to succeed in the District of Columbia, they need to be vetted with a host of local and federal agencies, because of its status as the nation's capital. The process of negotiating just city agencies can derail projects. Federal interest adds both challenges and opportunities. For example, it was interest in and funding provided by a local representative from Maryland that provided the initial funds for the South Capitol Street Gateway Study. Part of the early coordination involved consistent information provision, through meetings and briefings, to federal partners. By keeping the federal and local partners informed, key political will was available and able to be brought to bear at critical junctures in project development, particularly for funding.

In addition, the Department of Transportation was maturing as an agency. They had been diminished during previous decades, and the responsibility for major capital projects had been turned over to the federal department of transportation. In the late 1990s, they became a full department in the city government again and assumed the full authority of other state departments of transportations. Given the importance of the AWI, a specific team within DDOT was created in the Infrastructure Project Management Administration (IPMA). This team would be responsible for planning, designing and managing the construction of these special infrastructure projects that make up the AWI. The people assigned to the AWI team took their responsibility for delivering innovative sustainable transportation projects very seriously. They consistently implemented the policy direction, first articulated in the AWI Framework plan, and reinforced by the Mayor, the City Administrator and the Director of the Department of Transportation. The regularly articulated this mission to their agency partners, and worked diligently to make sure that policy was understood and integrated into the planning and design for the projects.

3 OTHER POLICIES THAT PROMOTE SUSTAINABLE CONSTRUCTION

3.1 *Context sensitive design*

As described by DDOT, Context Sensitive Design (CSD) is a part of the DDOT design efforts and the Context Sensitive Design Guidelines are included as a chapter in the DDOT Design Manual. These guidelines provide an additional resource in the design and planning process to achieve better and improved designs. CSD is a collaborative, interdisciplinary approach that involves all stakeholders to develop a transportation facility that fits its physical setting and preserves scenic, aesthetic, historic, and environmental resources, while maintaining safety and mobility. These are intended to inform the design decisions of staff engineers as well as consultants.

DDOT was not adopting a radical new standard, however, it was simply formalize an approach it had always taken. "The District Department of Transportation (DDOT) has always used Context Sensitive Design (CSD) in almost all transportation projects. DDOT's context sensitive approach extends from extended public involvement to preserving the historic character of the District, from avoiding adverse impacts on the natural parklands to enhancing multi-modal transportation options in every transportation project." (DDOT 2003) The procedures and policies promulgated internally made CSD a regular part of the design process. DDOT revised its Design Guidelines Manual and added Context Sensitive Design guidelines.

3.2 *AWI Architectural Standards*

DDOT created a comprehensive set of architectural and engineering standards for the AWI area, a major component of their sustainable transportation agenda. Sustainable transportation relies on a balance of landuse and transportation planning, the integration and enhancement of the local context--historic, scenic and natural environment, and guidance from community values. In essence, sustainable transportation relies on the criteria and goals defined in the Anacostia Waterfront Framework Plan. To help guide the selection of appropriate materials, DDOT created the Anacostia Waterfront Transportation Architecture Design Standards. (DDOT 2006). The process for developing the guidelines included a demonstration of sustainable materials and techniques previously unused in the District. A handbook that provided details about materials for roadways, streetscape, street furniture, landscape materials was completed in 2006. In addition, there is an internet based tool that enables planners and designers to consult tear sheets and specs for materials. The manual provides tools which are consistent with or exceed existing District policies and standards, provide users the opportunity to incorporate distinctive Anacostia Waterfront area features into the public right of way.

3.3 *Public Involvement*

It has been an important policy of DDOT in general, and the AWI team in particular, to consistently engage the concerned public at each step of the project development process. Staff tirelessly attend civic meetings, Ward functions, neighborhood functions to listen to the concerns of local residents, respond to questions, and engage them in discussion about the projects and how they will be implemented. DDOT has employed "town hall" and "civic fair" type all day meetings where every public project in a certain area, whether it is transportation, schools, libraries, or other utilities, attend and explain the project.

In addition, in conjunction with the first element of the South Capitol Street project to go to construction, the Near Term Improvements and the Frederick Douglass Memorial bridge rehabilitation, two outreach and education centers were created in storefronts in the neighborhoods both east and west of the river. These are places where the public can obtain up to date information on the project and learn about job opportunities. The Center includes a Visitors and Education Center and offices for local agencies. The centers also provide points of contact and serve as coordination points for projects being undertaken in the corridor by the Anacostia Waterfront Corporation, another important partner in the AWI transformation. DDOT will use the Center to manage the Two-Way Street Conversion of Martin Luther King Jr., Avenue, SE Streetscape and the 11th Street Bridges project.

DDOT also employed an innovative program to spur greater use of transit and ridesharing by commuters affected by the full closure for repairs of the Frederick Douglass Memorial Bridge. Modeled after a successful similar effort carried out by the Woodrow Wilson Bridge Project, DDOT's "Bridge Bucks" program will provide fifty dollars per month toward transit fares and vanpool fees to encourage commuters to switch out of their cars and into an alternative travel mode. By providing financial resources and personal advice on transit services, the program enables individual commuters to utilize alternative travel options that best work for their particular lifestyle—whether via rail, bus or vanpool. To raise awareness of Bridge Bucks and the July-August total closure of the Douglass Bridge, DDOT is launched a major public outreach campaign. This effort to ensure there are no surprises, a broad and aggressive campaign to keep the public informed of the closures, promote Bridge Bucks and commuting alternatives, and recommend detour routes. The campaign featured creative radio ads that are placed to catch the attention of drive-alone commuters who use the Douglass Bridge and to motivate a change in how they get to and from work.

4 PLANNING ACTIONS FOR SUSTAINABLE CONSTRUCTION

4.1 *Anacostia Waterfront Transportation Infrastructure Master Plan*

DDOT undertook to create a master plan for the infrastructure projects along the corridor. This step considered environmental impacts, construction impacts, and the most effective and feasible way to construct the range of projects in the corridor. The Anacostia Waterfront Transportation Infrastructure Master Plan is an umbrella document under which the collected transportation infrastructure projects in the Anacostia Waterfront corridor are described and organized. The master plan depicts the collective infrastructure projects in the Anacostia Waterfront corridor and lays out the planning and project development coordination that DDOT undertakes to accomplish both large and small infrastructure projects in an efficient and synchronized way.

All of the major transportation studies and projects in the corridor were reviewed and analyzed. A logical project sequence and timing was developed based on the set of infrastructure projects and constraints including cost, construction schedule, environmental impacts, funding and community interest. This project sequence provided a snapshot of DDOT’s project development activity. DDOT uses this transportation master plan as a tool in continued public outreach and agency coordination. A team of planners, financial analysts and experienced engineers created and updated the masterplan. This type of integrated team, a hallmark of DDOTs project approach, contributed to the creation of a plan that considered the range of necessary issues for project implementation.

4.2 *Continuous constructability reviews*

The South Capitol Street projects which have begun construction, the Near Term Improvements and the Bridge Rehabilitation received continuous constructability reviews during design. DDOT engineers from each element of the agency that needed to review plans at specific design stages were regularly involved in the process. This review and coordination allowed for more innovative stormwater capture techniques to be integrated in to the project. DDOT project engineers were comfortable with consultant designs, and agency coordination meant the utilities representatives at ease with more innovative techniques.

Bridge rehabilitation work was undertaken in a swift contracting process to take advantage of the limited time available during construction of a major new development in the corridor and complete the work prior to the arrival in the corridor of several new residential, entertainment and employment destinations. In keeping with a national effort to minimize the pain of the construction process upon surrounding neighborhoods, DDOT decided to allow full closure of the bridge for two summer months. There is a general decrease in traffic in July and August when Congress is out of session and related employment tapers off. In addition to careful timing of the closure, DDOT devised a suite of transportation mitigation measures and engaged in a comprehensive and ongoing public information campaign. Full closure of the facility during construction enables a shorter construction time, more efficient deconstruction and recycling of construction materials, minimizes the need for hauling debris or structures offsite for deconstruction, and improves worker safety.

4.3 *Financial*

All cities face the difficulty of maintaining aging infrastructure. The AWI is an ambitious capital program requiring staff resources and significant funding well beyond the level of the standard transportation program. Once the feasibility study was complete, and a range of projects began to take shape, DDOT began considering innovative means to finance the AWI and South Capitol Street. One benefit to the project was positive opinion of it and support by key members of Congress and the local government. Consequently in major transportation spending bills, the project received portions of discretionary funds.

This provided DDOT with an opportunity to continue project development without dipping into their regular program funds. They also "pulled out their pockets" and found projects with surplus or unused funds which could be reallocated to the planning for South Capitol Street projects. Although they had funds to continue project development, DDOT began to considering innovative finance techniques, tools recently approved by the federal government, to fund the AWI and South Capitol Street. These included Grant anticipation revenue vehicles (GARVEEs), public private partnerships (PPPs), and a loan derived from the Transportation Infrastructure Finance and Innovation Act of 1998 (TIFIA). This provides Federal credit assistance to large-scale highway, transit, passenger rail and intermodal projects. A TIFIA loan, line of credit or loan guarantee can be used by public or private transportation sponsors to complete a project's funding package. Other options were looked at including; increased taxes or new taxes, including sales taxes; and user fees, including tolling, area charges, cordon charges, and commuter taxes. These are politically unpalatable in the District of Columbia. Opportunities for development-oriented sources of funds (such as Tax Increment Finance (TIF) and Development Impact Fees) on land owned by or to be transferred to the District, particularly in Poplar Point were also actively considered.

5 SUSTAINABLE OUTCOMES

Early awareness of potential build schedules allowed coordination of schedules to minimize disruption to the public and provided improve construction staging efficiencies;

Coordination of maintenance of traffic for bridge rehabilitation, coordination with major ballpark allowed for more aggressive, more cost effective construction with minimal disruption to neighborhoods;

Early coordination meant that some contracts could be amended before being let for bid. This meant that new elements, such as the lowering of a viaduct structure, could be undertaken. This allowed for quicker construction time, less cost, and better access to surrounding new development. The sooner new development comes on line, the sooner new tax revenues will be added to the District's general fund and to special assessment areas;

In addition to considering impact fees, coordination with developers has meant that once the project is in place, developers will not need to disrupt the new roadway with utility cuts;

Stormwater retention and management. Improved catch basins will filter stormwater before it is released into the main system, slowing the rate of discharge and filtering out debris. Currently runoff flows into sewers and is treated at a plant. The direct impact of the project on the entire Anacostia Watershed is anticipated to be positive because of improved management techniques for stormwater. It is likely that the local tidal Anacostia watershed would benefit from decreased runoff and improved stormwater management.

Sustainability recommendations for a social housing project: Barreiros, Vitória (BR)

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ABSTRACT: This research is part of an ongoing Master dissertation that aims to propose a set of guidelines to evaluate the sustainability and inform the design of social housing projects in Brazil. This paper presents the development of a questionnaire, based on the analyses and categorization of existing guidelines proposed by Brazilian researches and some of LEED's criteria, and the results achieved with its application in the Barreiros' Residential Development community (Vitória, ES, Brazil). As part of the results, it is presented an evaluation of Residential Barreiros, with a description of the sustainable design solutions in place and also the interviewees' verbalizations and perceptions regarding the development. In addition, it is presented a list of recommendations to contribute to Barreiros' sustainability.

1 INTRODUCTION

In a society marked by the adoption of an unsustainable economic and environmental model the civil construction industry is one of the most responsible for the environmental impacts. The natural resources invested all over the world in the construction industry absorbs 50% of the world resources (EDWARD, 2004). To build using less amounts of natural resources is today the biggest challenge in civil construction. This becomes more complex in undeveloped countries where the housing deficit and coming up constructions are much bigger than in countries with advanced economic conditions.

With the increase of the world population, the cities are also growing extensively and suffering with higher population densities. This excess is more noticeable in urban areas which are the main responsible for environmental problems that threat the Earth (RUANO, 1999). According to projections of the United Nations for Human Habitat (UN-HABITAT), in 2030 approximately 40% of the world population will need houses and basic infrastructure services. Therefore 96.150 units per day would have to be built to attend this population, most of them low income housing.

In Brazil, the population deficit reaches 7,7 million of houses, of which 5,5 million are in urban areas (ONU 2006). This population concentration increases the demand for houses and puts pressure on basic infra structure, which tends to be either insufficient or below environmental standards, if not inexistent all together (ANDRADE; ROMERO, 2004).

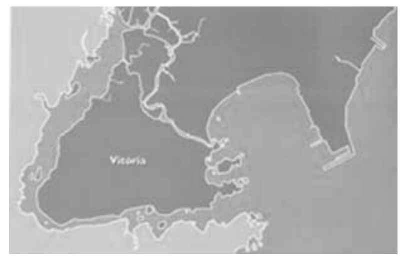
Strong urban growth has severe impact on the environment. For Bill Dunster (in GURFINKERL, 2006) it is necessary to assure that resources are being produced locally, to reduce the use of private vehicles and above all to learn to share, therefore contributing to the reduction of air pollution, lowering levels of poverty and traffic jams and consequently helping achieve better quality of life . According to John (2000), the use of recycled materials and water and energy efficient equipments, as well as the adoption of architectural solutions that takes advantage of the natural light and ventilation are some of the alternatives that will contribute to the sustainability of the construction industry in the future.

In the last 50 years, the life expectancy went from 46 to 64 years (EDWARDS, 2004). This social aspect indicates it should be expected an increase on the demand for illumination, transport, heat, etc. Going through some aspects with the uncontrollable use of natural resources and urbanization growth, we understand that it is necessary to create new ways for men's life.

Sachs (1993) understands that for our society to achieve sustainable development we should look at five dimensions: social, economic, ecologic, spatial and cultural. According to Sattler (2002) all housing projects should always be built abiding to sustainable standards in all these dimensions. In addition, he stresses that these dimensions should go beyond the housing unit and encompasses the surrounding environment, as well as the relationship between them.

To understand the reality of the environment of a city you need to go back to its origins. Vitoria, the capital of Espirito Santo, is the third oldest capital of the country, founded on September 8, 1551. It is located at latitude 20º19'10" and longitude West of Greenwich 40º20'16". The city center is located in an island of 88,77 km². In 2000 its population was 292.304 inhabitants and it's estimated that it will reach 317.085 residents by 2006 (IBGE, 2006).

In Vitória, problems with urbanization and poverty started to be noticed in the last 50 years, when the low income population started occupying areas located in hillside sites, which represent more than 70% of the total area of the municipality. In the 1960s informal housing had multiplied and reached the mangrove areas (MARTINUZZO, 2002).



Figures 01, 02 and 03 – Location of the city of Vitoria in relation to the state of Espírito Santo and Brazil. Images: MARTINUZZO, 2002, p. 18.

In the 1980s it became apparent the polarization between the poor and rich regions. and some government actions started in this period proved to be positive experiences. One of them happened in the São Pedro Area, which received many prizes and took part of the 2nd United Nations Conference for Human Settlement, Habitat II, in 1996 in Istambul, Turkey. In 1996, the municipality of Vitoria (PMV) started an Integrated Program for Social Development, Urban and Environmental Preservation of the Areas Occupied by Low Income Population, known as "Projeto Terra". This project aims to work towards inclusion: to include the poor regions into the city scene, into a quotidian of civil rights and of good quality public urban spaces.

The city regions chosen to receive social, economic, urban, cultural and environmental programs totalize 15 areas called poligonais and are signed in the map. Poligonal 11 presented many residents living in wood houses on piles (constructive system for residences located in flooded areas, built on top of high pilings to avoid water.) in mangrove areas. The mangrove is an important ecosystem for the breeding feeding and growing of various animals, and part of bird migration routes, besides being responsible for enriching seawater with salt nutrients and organic material. These houses were reclaimed by the government and the residents transferred to new houses in a village of 70 twin houses known as Residential Barreiros, This place was chosen as a case study to investigate the sustainability of social housing initiatives.

2 OBJECTIVE AND THEORETICAL FRAMEWORK

The objective of this paper is to examine the sustainability of the Residential Barreiros. First of all a review of literature on social housing, sustainable architecture and sustainable development was conducted to identify criteria used for the evaluation of sustainability of constructions. Having identified the criteria, they were used to develop the questions used in the interviews with the residents. They were organized in a spreadsheet distributed in 4 themes: relationship with the house; maintenance e protection of natural resources; outdoors; social-economic and cultural questions. They were used to described the development of this questionnaire and the results of its application at the Residential Barreiros.

A semi-structured interview was adopted to search information from the population. However, the comments were left open, so that the perceptions could be expressed. The houses and interviewes were randomly selected; one resident per house was chosen to talk to the interviewer. People over 17 years old were targeted. It is necessary to mention that the transcription were verbatim, even with orthographic and grammatical mistakes. During the interviews, 56 residential units were involved, which represents 80% of the total 70 units. 84 questions were prepared distributed into the 5 groups: the 4 described above and another one containing personal information about the interviewee.

3 DESCRIPTION OF THE OBJECT OF STUDY

In the swamp area of Poligonal 11 where the Barreiros Residential is located, the invasion began in 1960 resulting in shelters alongside the channel, shown in figures 04, 05 and 06. In 1999 they began registering families to be re-settled, with priority for families with monthly income between 0 to 3 minimum salaries. The minimum salary is determined by the Brazilian government and refers to the minimum wage one earns for 40hs of work a week. Its value is R$380,00 which correponds to €139,53 according to the Federal Bank of Brazil (in 04/10/2007, 1 euro = R$ 2,72).



Figures 04, 05 and 06 – Original shelters in swamps, before the process of intervention proposed by Projeto Terra. Images: MARTINUZZO, 2002, p. 25.

In an area of 7.440,30 m², 70 residential units were built with lots of 49,5 m² approximately. The residential has 70 two-storey row houses. On the main floor there is the living room, kitchen and a bathroom; the two bedrooms are located on the upper floor The new constructions were approximately 600 meters far from the previous area, therefore within the main objective of the Habitar Program – Brasil/BID, that is to promote quality of life for the families, by settling them in the same region of the intervention. The Habitar Program – Brasil/ BID – Interamerican Bank of Development - is managed by the Brazilian Ministery of Cities. It funds projects that aim to generate income and to improve the living conditions in settlements located in risk or poor areas. In this way it funds social housing projects, urban infrastructure, and the restoration of degraded areas, among other initiatives (CIDADES, 2006).. By the beginning of 2002, all the families were already settled in the new urbanized area. In order to help them relocate and get used to the new reality, they received support from a team of social workers of the municipality. Up to now the community is the receipient of their support: programs of environmental education and empowerment - income generation and participation - are still offered to them.

4 LITERATURE REVIEW

The references used are presented in table 01, together with its main focus, and its thematic. The questions on the contents similar to the questionnaire were grouped by topic (column 4 of table 01).

Table 01: Sustainable architecture: Referential groups and proposed groups

References	Main focus	Thematic	Proposed groups
ALVAREZ, 2002	Comfort is associated to “well-being on thermal, acoustic, ergonomic, tactile, psychological and visual aspects.” (ALVAREZ, 2002, p. 121). It is emphasized the quality of residence and selection of materials, and the need to think at the urban scale.	Quality of residence Ventilation Thermal comfort Rationalization of natural resources Materials Urban Scale	1. Identification; 2. Relation with residence; 3. Conservation and protection of natural resources; 4. Surrounding of sustainable housing; 5. Social, economic and cultural questions
SATTLER, 2002	Solutions prioritize the use of sustainable resources, the the minimization of energy consumption, the management of solid and liquid wastes, the use of low environmental impact constructing materials, and of productive landscapes, and the production of local food and as well as towards social and educational questions.	Environmental comfort Climate factors Reutilization of resources Constructions Landscaping Social, economic and cultural Urban Scale Sustainable Communities	
CORBELLA; YANNAS, 2003	The sustainable architecture is related to environmental comfort and points to design solutions for improving human well-being and quality of life	Thermic performance Visual Comfort Acoustic performance	
LEED (USGBC, 2006)	The method outstands strategies for local sustainable development , water savings, energetic efficiency, selection of materials and the environment quality of the internal air besides the evaluating the Green Building through a certification. It is a sophisticated system for this research. However, the sustainable criteria contributed as a theoretical basis.	Sustainable sites Water Efficiency Energy & Atmosphere Materials & Resources Indoor Environmental Quality Innovation & Design Process	
SAASHA (SBAZO et al., 2005)	Social Human and Environmental Analysis and Evaluation. It establishes criteria for construction of sustainable buildings in developing countries of tropical climate, namely Brazil, especially in São Paulo.	Surroundings Construction Materials and techniques Human and cultural aspects	

5 THE QUESTIONNAIRE

In group 1 – identification – questions such as age, gender and level of education help define a preliminary portrait of the interviewee. In group 2, relations with residence, questions relate to a comparison between the two residences (old and new), and to the level of involvement and participation of the user during the design process and in the effective construction. This group also deals with aspects related to environmental comfort: thermal, acoustic and lighting. It is investigated the presence of natural ventilation and direct illumination on working areas, the existence or absence of transparent surfaces necessary for letting in sun radiation, and the users' perception of noises, among others.

Group 3 is comprised of questions related to conservation and protection of natural resources with emphasis on its use. It evaluates the knowledge and acceptance of the resident about the use of energy efficient equipments and green or recycled products, about recycling of liquid and solid wastes, the use of vegetation to improve the local climate and of productive landscaping. On group 4, the focus was on the outdoors. Questions refer to the universal accessibility problem, illumination, cleaning and maintenance of open and collective spaces, the existence or not of communal living areas, the access to services, the relation of the residence and the city, etc. Finally, group 5 introduces social economic and cultural questions; it looks for information on the possibility of generating income through small family businesses or the availability of a communal space where this could happen. It also aims at verifying the participation of the residents in decisions related to the community. In addition, group 5 investigates the respect for cultural, historical and natural features of the population, for the existence, for example identification with local architecture.

6 RESULTS - APPLICATION OF THE QUESTIONNARY

Of all the interviewees, 7% have never studied and 52% have not finished elementary school. Despite the low level of education, the interviewees said they were aware of some aspects of "sustainable architecture". The environmental education programs promoted by the municipality may have contributed for this factor. Most interviewees mentioned the workshops and public meetings held by the municipality, which indicates the government's high level of commitment.

According to the Group 2 questions, the new houses have contributed to a better way of life of the residents and community. Of the interviewees 84% have said that the house of "Projeto Terra" (figures 07, 08 and 09) is better than the old one. The interviewee E-02 said "if I look back to the old house, I can say that I'm in heaven". As for E-54 "The house is better because it used to be a wooden shelter". It seems that a masonry house is a dream home that provides a better quality of life. The seems to have entitled them with the citizenship forbidden to whom live in swamps.

Figure 07 – View of Residencial Barreiros Residence.

Figure 08 – Houses in Residencial Barreiros.

Figure 09 View of one side of the road.

As for the participation of the users, it was noted that during the design phase the families didn't have any relevant involvement. Only 20% of the interviewees considered themselves involved in some way. One result of this participation is exemplified by interviewee E-26, "the only opinion we gave is that they wanted to make only one room and we asked for two". The interviewee E-30 ads: "we signed a petition to have two rooms. Only after a long dispute we were successful". Another testimony showed to be eager to contribute: "They didn't ask our opinion; I had a whole lot of requests, it could have been something good that could had helped them" (E-35). During the construction stage everyone could visit but not participate. The participation would be possible afterwards, as the house did not tiles or plaster. The interviewee E05 that works with civil construction had some "savings" and was able to made some improvements before he moved. It seesm that the residents work force could have been better used during the construction phase, because 50% of the interviewees – women included- said that they had already helped building houses of friends and relatives, and 66% said that they were familiar with the materials used.

As for ventilation, 43% of the interviewees perceived their houses to have a regular ventilation, while 43% perceived it to be good. It seems to deserve attention the fact that the ventilation is not perceived to be evenly distributed between the two floors: "We have more breezes in the rooms. Down here we don't feel" (E-26). For the interviewee E-10: "My room is cold at night". As for lighting, 75% of the interviewees said having good natural lighting. According to interviewee E-15: "Downstairs with the ceiling and walls painted in white makes it is more bright. Upstairs it is not as much; I think the brown tiles let the light escape". We see here a perceived relation between visual comfort and the used of light colors.

Conversely, there is strong dissatisfaction with the houses' acoustics , Noise from neighbors, (mentioned by 36% of interviewees) and from the bars located too close to the residences (15 % of interviewees), were pointed as the most annoying sources of noise. Most of the interviewees (52%) have mentioned that the noise persists even with the windows and doors shut. According to interviewee E-20, “the problem is the half dividing wall between two houses”. The interviewees have made the point that the dividing walls in row houses help the propagation of sound. It should be noted that the original project presented double walls that were not built. The fact that the walls don’t have plaster and the houses have no ceiling beneath the roof also contribute to propagation of noise. Interviewee E-01 said that he got good results in regards to acoustics after plastering the internal walls and, he also says “when the other residents do the same it will be even better”. But interviewee E-36 says that he “... has no privacy… To talk in the rooms you must whisper. For intimacy you must go downstairs; without the roof the comfort is affected”. When questioned about possible improvements, interviewees have ranked the installation of flooring and burglar bars, and an addition to the existing built area number 01, followed by the plastering of walls and main floor ceiling, these last two related to acoustics improvements. For interviewee E-06: I would change the roof, plaster the walls and paint the living room. But all depends on money.

In talking about some questions of group 03, 59% of the interviewees said to have knowledge of other energy resources. When asked about using equipment with better energetic efficiency, the results were encouraging. It was noted for example that 91% knew about the low consumption of fluorescent lights and 81% of the houses have this type of lamp in the 05 rooms. In this regard, it is important to acknowledge the joint educational campaign by the municipality and the Electricity Company to promote energy efficiency: they have promoted the use and distributed lamps and new fridges. Some interviewees showed that even before the campaign they were aware. “When we moved here we bought fluorescent lamps at Carrefour for the whole house because we saw on TV that they save energy” (E-28).

Regarding water, at the Residential it is subsidized; the habitants don’t pay proportionally to what they use. This is a municipality decision that creates debates among the residents themselves. On one side there is the resident concerned in saving it: “People here use a lot of water, they waste” (E-23); “As for me, they should legalize everyone’s energy and water, so that we don’t pay for those that don’t pay their bills properly” (E-18). On the other side, there are those that don’t worry at all with this: “Sometimes I waste water because here we don’t pay” (E-09).

As mentioned above, the user’s participation took the form of working on the houses’ finishing, and only after the municipality handed them the keys. It included the pavement of external areas, the construction of front walls, plastering and tilling etc. It was observed the used of recycled construction materials. One example is of interviewee E-17 who used remaining tiles of the construction company where he worked (figure 10). The problem was that he used it to pave the permeable part of the lot, without knowing that he was contributing to future problems in natural drainage. Based on this, one can say that it might be necessary to improve efforts and investments in different aspects of environmental education.

When analyzing the residences’ surroundings, group 04, it was noted the lack of trees in the yards and on the streets, which gives the residence a dull aspect (figure 11). In the lots, we noted that 20% of the interviewed residents had some type of vegetation planted directly on the ground, mainly productive species. In the small permeable area of approximately 15 sqm were found orange, papaya, cocoa and avocado tress, medicinal herbs, pineapple and sugar cane, among others (figures 12 and 13).

Figure 10 – Use of recycled material in backyard.

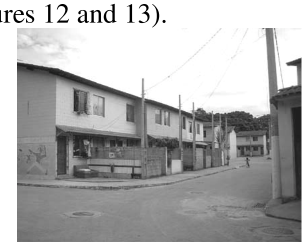


Figure 11 – Lack of trees in the streets: dull aspect.

Figures 12, 13 – Example of productive landscape, planted in small areas (sugar cane and cocoa).

When questioned about trees, 18% of the interviewees seem to be unaware of the benefits of trees planted nearby; 69% believe that trees are important for its shadows in hot sunny days (E-

17). The interviewee E-04 said: *I am thinking of breaking this pavement here and planting a tree to see if it helps with the heat, because the afternoon sun makes us suffer*". On the other side, safety concerns has made interviewee E-20 prefer not to have trees: "*trees on the street work as hiding spot. Thank God we don't have trees here"*.

As for group 05, we noted that the habitants are still not organized around local leaders, although social assistant services are in place to help create this. In relation to cultural traditions, the facades are merely a result of the plan, without any decorative or symbolic element.

On recycling, 96% were aware that it can generate an extra income; 32% had already worked with recycled materials (most were craftwork). Interviewee E48 complemented: *"I lived in Curitiba, and there I worked with trash. Here trash is rich and there they don't have this. Here you can earn money because people throw out many good things that you can recycle"*. In answering a direct question about the word sustainability, 25% of the interviewees mentioned they have already heard about this: "yes I have heard about in workshops at CST" (E-31) - CST: a steel plant company located in Vitória that is the world biggest producer of steel; "*yes I heard but I didn't understand exactly what it meant but I'm going to find out*" (E39). It seems that although it is a new and complex topic, environmental problems and their solutions are calling the attention of the ordinary citizen

7 FINAL COMMENTS

The compilation of sustainability criteria informed the development of the questions used in the evaluation of Residential Barreiros. Some recommendations aiming the betterment of residents'quality of life based on sustainability principles are worthy mentioning:

- Use of sound proof efficient materials for plastering of walls and ceiling;
- Use of light colors indoors;
- Prohibition of 100% pavement on front and backyards;
- Incentive to productive landscaping;
- Landscaping in common areas;
- Creation of specified areas for recycling materials disposal;
- Creation of a space for workshops and activities that might generate income;
- Promote more workshops and meetings towards attitudes and environmental consciousness water preservation, energy saving, recycling, etc).

In general, at Residential Barreiros, we identified some actions related to sustainable practices. Most residents do contribute. Public agents are involved in conducting talk conferences and workshops, but still in a modest way. It is necessary to present sustainability initiatives related to their local reality, in order to improve their quality of life, not to mention the overall environmental conditions. The results obtained support the idea that it is necessary to involve public agents in actions and policies to implement sustainable construction.

REFERENCES

Alvarez, C. E. de (coord.) 2002. *Habitação Popular Ecológica: desenvolvimento de modelos baseados nos princípios da sustentabilidade e nas características ambientais específicas de Vitória*. v. 1. Research project. Vitória: Laboratory of Planning and Projects.

Andrade, L. M. S. de S.; Romero, M. A. B. 2004. Desenho de assentamentos urbanos sustentáveis: proposta metodológica. In: *Conference Latino-Americana de construção sustentável; Encontro Nacional de Tecnologia do Ambiente Construído*, 18-21 July.

CIDADES 2006. *Ministério das cidades*. Available in: <http://www.cidades.gov.br>. Consulted in: 28/12/2006.

Corbella, O; Yannas, S. 2003. *Em busca de uma arquitetura sustentável para os trópicos: conforto ambiental*. Rio de Janeiro: Revan.

Curiel-Carías, E. C. 2005. The building concept in hybrid systems constitution (Kiron system). In: *Building and Environment*. v. 40, n. 09. September 2005, 1235-1243

Edwards, B. 2004. *Guía básica de la sostenibilidad*. Barcelona, Gustavo Gili.

Gurfinkel, C. 2006. Nova consciência, novas prioridades. In: *Arquitetura e Urbanismo*. n. 142, 52-55.

IBGE - *INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA*. Available in: <http://www.ibge.gov.br/home/>. Consulted in: 12/27/2006.

John, V. M. 2000. Construção e Desenvolvimento Sustentável. In: *Qualidade na construção civil*, n 23, ano III.

Lodi, J.B. 1998. *A entrevista: teoria e prática*. 8. ed. São Paulo, Pioneira.

Martinuzzo, J. A. 2002. *Projeto Terra: Vitória para todos*. Vitória: Prefeitura Municipal de Vitória-ES.

ONU - *Organização das Nações Unidas*. Available in: http://www.onu-brasil.org.br/view_news.php?id=2875/. Consulted in: 12/21/2006.

Ruano, M. 1999. *Ecourbanismo entornos humanos sostenibles: 60 proyectos*. Barcelona: Gustavo Pili.

Sachs, I. 1993. *Estratégias de transição para o século XXI: desenvolvimento e meio ambiente*. São Paulo: Studio Nobel, Fundação do Desenvolvimento Administrativo.

Sattler, M. A. (Coord.). 2002. *Projeto CETHS: Centro experimental de tecnologias habitacionais sustentáveis. Relatório de Atividades*. v. 1. Porto Alegre: NORIE/UFRGS.

Sbazo, L. at al. 2005. Sistema de Análise e Avaliação Sócio - Humano - Ambiental: SAASHA. In: *Conferencia Latinoamericana de Escuelas y Facultades de Arquitectura*, n. 20.

USGBC-U.S. *Green Building Council*. Available in: http://www.usgbc.org. Consulted in: 11/10/2006.

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Sustainable housing: from consensual guidelines to broader challenges

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ABSTRACT: Changes of global climate, exhaustion of natural resources, pollution and destruction of natural habitats are clear signs that human activity is becoming unsustainable. Facing these symptoms of global crisis, it has become consensual that measures to mitigate such problems are needed. The housing sector is a major consumer of resources consequently it is a key area to promote environmental sustainability. The concept of sustainable housing derives form the broader concept of "sustainable development", being also divided in three domains: social, environmental and economical. To promote sustainable housing many guidelines can be set up, having impacts on urban, architectonic and construction levels. These are the themes that this paper intents to discuss in order to clarify some fundamental concepts and provide information about different options.

1 INTRODUCTION

The complexity of housing sector makes the concept of “sustainable housing” difficult to synthesize. However it is important to have a broad perspective of the issue in order to establish objectives and choose priorities.

This paper intends to clarify some fundamental concepts and provide information about different options. For this purpose the paper discusses the following questions: Is the actual development model sustainable? Which are the signs of unsustainability? Which guidelines should be used for the production of more sustainable housing? At which scales are main decisions for housing sustainability taken? What is the contribution of housing rehabilitation? To conclude some final remarks are presented.

The paper is based on the results of the study "Environmental sustainable housing" developed at the National Laboratory of Civil Engineering (LNEC), with the support of the Portuguese Foundation for Science and Technology (FCT), in the framework of research project “Housing for the future”. After the conclusion of the research project the authors continued the research on the subject going deeper into some of the previous results.

2 IS THE ACTUAL DEVELOPMENT MODEL SUSTAINABLE?

Many signs show that the production and consumption standards of industrialized countries, reproduced by developing nations, are becoming unsustainable.

The increasing use of fossil fuels to supply energy for industrialized societies is raising the concentration of gases, such as carbon dioxide, in the atmosphere. It is now widely accepted that this excess of carbon dioxide intensifies greenhouse effect and is responsible for global warming. Global warming motivates important environmental changes, such as melting of polar ice and glaciers, sea-level rise and a higher frequency of extreme climatic situations (hurricanes, torrential rains that cause greater floods and long periods of drought that propitiate the advance of desert areas). Atmosphere is also affected by the presence of other gases that, beyond aggravating greenhouse effect, contribute to the deterioration of air quality, endangering the health of human beings.

Another factor of unsustainability is the exponential increase of population that aggravates the pressure over natural resources. Virgin territories are being used for agriculture and being occupied by the expansion of human settlements, motivating a progressive change or destruction of natural habitats, which endanger the survival conditions of natural fauna and flora. The population increase and the economic activity acceleration are also increasing the consumption of non-renewable resources, such as oil, coal and natural gas. Major cities, where most of the population concentrate, produce massive amounts of waste that may contaminate the ground, the air and the water, demanding more energy for its recycling. A wider occupation of the territory is also contributing to contaminate water reserves and to reduce their replacement by natural infiltration in the ground.

Finally, regarding social and economic conditions, there is a poor equity in the access to resources and knowledge, what is reflected in the increase of regional asymmetries and local inequalities. Furthermore, cultural heritage faces the risk of homogenization and the built heritage faces the risk of destruction, having both to be protected because future generations also have the "right to memory".

As a conclusion, a development model that privileges immediate individual welfare was adopted, but environmental, social and economical signs suggest that one day human beings may have difficulty in adapting to a habitat mainly shaped by their predecessors' actions.

Many of the unsustainability signs, observed at a global level, are also becoming evident in Portugal.

Regarding environment, heat waves are becoming more frequent (aggravating the violence of forest fires during summer), after more than fifty years of interregnum it snowed in Lisbon in two consecutive years, and along the Portuguese line coast erosion is beginning to endanger buildings and populations.

Furthermore, an extensive and undisciplined use of the territory occurred during the last few years, being housing construction the prime purpose of this use. However, the repetition of conventional building typologies is dominant, proving that environmental performance and adequacy to new forms of family are still not priorities of housing developers. Meanwhile, a gradual degradation or destruction of the ancient housing stock is continuing, despite some recent political initiatives.

Concerning life style, the majority of the population seeks for more comfortable living conditions even if that requires a high consumption of natural resources, some people wish to live surrounded by natural habitats although destroying them in process, private automobile (already dominant as the private means of transport) is increasing its importance, and typical habits of a consumerist society are becoming the norm.

Finally, situations of poverty and social exclusion still persist and a gradual ageing of population is occurring.

However, the awareness of public opinion about sustainability problems is increasing as environmental and social crises starts to affect comfort and security levels and is evidenced by mass media and sensitization campaigns. Nowadays, environmental and social problems are frequently headlines in television news, first page in newspapers and magazines, and subject of films and documentaries. Environmentalist movements and non governmental organizations, seen in the past as radical or utopian, have today an active role in discussion forums. Information and sensitization campaigns about environment and citizenship, mostly directed to young persons, are recurrent.

3 WHICH GUIDELINES SHOULD BE USED FOR THE PRODUCTION OF MORE SUSTAINABLE HOUSING?

The public opinion awareness towards sustainability problems is a capital that should be invested in order to promote more responsible behaviours. It is necessary to capitalize this goodwill credit into concrete actions, leading to a more sustainable development.

The concept of sustainable development is widely understood as the "development that meets the needs of the present without compromising the ability of future generations to meet their own need". This concept was accepted internationally, being usually divided into three domains: social, economical and environmental.

The characteristics of our built environment are essential to the achievement of sustainable development objectives. These include cutting greenhouse gas emissions, reductions in pollution, conservation of natural resources, and cohesive and inclusive communities. Housing in particular can contribute significantly to sustainability because: it consumes large amounts of resources in its construction, maintenance and use; it is a fixed asset with a long life; and it has a central importance to life quality of people with implications in other sectors (transports, health, employment and community). The concept of sustainable housing can also be divided into three domains: environmental sustainability means the reduction of the negative impact in the surroundings and in natural resources; social sustainability means designing for the present and future needs of users and community, and economical sustainability means cost efficiency over the life of the building.

Having established the concept of housing sustainability and recognized its benefits, the next step is to set up appropriate design and construction guidelines. The following sections briefly present some guidelines to improve environmental sustainability of housing.

3.1 *Settlement as balanced use of soil*

Soil is a limited resource, moving in cycles of erosion and sedimentation which are slow on time. To accelerate erosion of soil means to consume the biological time that keeps this natural resource available. Occupying and urbanizing soil in a sustainable way demands to respect its vulnerabilities and to predict forms of restitution of its original quality and state. Such intents are not compatible with the current tendency of occupation of coastal areas and river margins under flood risk.

Construction and infrastructure affects the use of soil for long periods of time, so it is strategical to use already infrastructured soil (brownfield) to (re)construct housing, consolidating old urban grids or transforming obsolete industrial areas. To densify and rehabilitate, renewing or replacing buildings is one form of actualizing the existent city profiting from compromised soil, infrastructures and nets of transport that serve it.

The way each housing settlement occupies land not only has consequences over soil consumption as physical resource, but also indirect effects on climate and transport nets efficiency with important consequences of energy demand of residential areas:

a) The relation between climate and soil occupation is complex and dual. In one hand each territory has its specific microclimatic conditions that have to be known, in the other hand this microclimate is mutable and options taken on land occupation and urbanization will directly influence it.

b) The relationship between housing settlement and transport is fundamental, and each time more important for urban sustainability. Reducing energy used for travelling inside the city, minimizing distances with higher urban densities and mixed uses of soil, promoting the use of public transports, and creating conditions for using clean means of transport are guidelines to plan uses of soil that can increase the quality and sustainability from housing settlements.

3.2 *Energetic efficiency and autonomy*

Morphology, typology and construction of residential buildings allow improving energy efficiency of housing, achieving high reductions on the use of energy, minimizing the emission of Green Housing Effect Gases and providing a bigger self reliance on energy.

Improving energy efficiency and autonomy in housing depends on two main aspects: the reduction of energy demand (that implies conservation, protection and rational management) and the use of local sources of renewable energy (which implies self-generation in passive and active forms of renewable energy).

Diminishing energy used in buildings requires the improvement of local microclimate, assuring solar protection and right orientation of buildings (reducing shadows and benefiting from solar gains and natural ventilation), building with high thermal inertia, providing adequate thermal insulation, integrating more economical equipments and control devices. However, even if demand is reduced in housing through the above guidelines, it is still very relevant the use of renewable and local energy. Self-generation of usable renewable energy requires the integration of spaces and equipments that take advantage of natural energy sources, benefiting from passive solar energy, privileging natural ventilation, and incorporating technologies for solar water heating and electric energy production.

3.3 *Hydric cycle management*

Rational management of water cycle and protection of hydric resources on the urban environment depends on the characteristics of the supply, drainage and sewage system. On these fields alternative procedures can offer a better hydric balance, through the following strategies:

a) Increasing natural water retention through green surfaces (horizontal as vertical ones) and direct infiltration through the assurance of minimum levels of permeability of soil in connection with the net of aquifers;

b) Collecting and reusing rain and drainage water is one of the most ancient strategies of sustainability, in particular, at the dry regions. The integration of rain water collectors on buildings further than to allow the water reuse on irrigation can also permit the energetic efficiency, providing passive cooling and allows neutralizing strong effects of internal micro climate.

c) Sorting out waters with different levels of contamination, managing sewage on eco-efficient ways is crucial for sustainable management of this resource. Grey water and black waters are not only waste but they are also resources. Grey water can easily be treated by biological processes where organic substances are absorbed by the action of aquatic plants. Black water can be treated on compost centrals that can provide gas for domestic use. Further on, black water includes also other resource, not energetic but material: the organic substances that can be of much use on local agriculture since their availability on the Planet is reduced.

d) Reducing consumption and waste of drinkable water is another good practice of hydric cycle management, and it is possible to implement it through the use of more efficient equipments, of intelligent systems of supply and management and also through campaigns near from the local communities. There are still many things that we do at home and at our residential area with high quality drinkable water, which could be done with recycled water, mostly on washing and cleaning tasks.

3.4 *Materials-waste cycle management*

Half of the total of raw materials extracted from the Planet is used to construction and more than half of the waste we produce comes from this sector, where housing has a great role. Reducing such an impact demands strategies that follow the example from the biosphere and intend to close the cycle of materials, minimizing losses during the life time of a housing unit as from a global residential area. These strategies are the following:

a) Ecologically selecting building construction materials: Only materials of low environmental impact during the totality of there life cycle (production, transport, use, maintenance, destruction, elimination) should be used in housing construction and use. Several factors are implied on the environmental impact of a certain material like the direct impact of its extraction, the nature of the resources requested on its production, the CO_2 emissions produced, distances and ways of transport used to distribute, risks for health, possibility of its direct reuse, the recycling potential and the “environmental performance potential” (contribution of the material for the environmental performance of the building during its use);

b) Converting waste on resources, “closing the loop” of construction materials: Waste is one of the biggest problems of our industrialized society and it will be the resource of the future. Housing as human activity implies the use and waste of several materials consumed in daily life, but also the materials applied on housing main physical infra-structure (buildings and public space). These materials are converted in waste after producing the utility of housing. “Closing the loop” means to make from construction waste useable materials again, recycling on an intensive and global way, from the stones of the sidewalk to the glass of the windows. For this purpose efficient recycling systems on construction and deconstruction sites are needed as specific strategies for maintenance, reconstruction, rehabilitation and demolition of residential buildings. Obsolete residential buildings can be seen not as waste but as resources, reusable through housing rehabilitation projects;

c) Minimizing domestic waste: Management of waste produced on daily life is a growing problem with increasing costs. On residential areas separation and efficient collecting are big steps, but these strategies are not enough and should be complemented with incentives for waste reduction and direct self recycling. Local recycling allows production of organic compost on green areas as transformation of waste and energy or fertilizers, reducing waste in general even before needing recycling.

3.5 *Optimization of constructive and spatial solutions*

Since housing production consumes big quantities of materials and results on big quantities of waste, more efficient construction systems using pre-fabricated elements on assembling and dis-assembling housing units, while assuring comfort and a good energetic performance during use, are also one aim of sustainability. Such aim can be accomplished through several ways:

a) Industrialized prefabricated constructive systems for housing production can optimize processes of project, construction, maintenance and deconstruction. This type of construction allows constructing housing units, or housing compartments, assembled on construction site. However, industrialized construction needs to be light-weight, for what it can achieve lower energy efficiency than conventional one, mostly in warm climates, due to occupation performance. Prefabrication is not necessarily a high tech tendency, and it can be of big utility in situations of limited resources, as on post catastrophe scenarios.

b) On design, the modulation of housing allows to study, design and to produce with big precision the module and assure its optimal environmental performance. Also during construction time there are advantages, for modulation allows standardization, reduction of work needs, minimization of material waste and better control of contamination of the building site. During maintenance and on the final of the useful life of the building the deconstruction of modular construction can also be more efficient on materials management and on its subsequent reutilization.

c) Flexibility from housing spaces can increase the time life of the building, extending materials life cycle. Housing square meters are a scarce resource that should be optimized as others. Flexibility can be achieved through neutral and polyvalent spaces – passive flexibility – or through mobile elements that allow the transformation of the housing unit – active flexibility. The second strategy can produce daily, seasonal or annual transformations of the housing unit that increase its adaptability to the user and its changeable needs. This allows saving energy and resources, since people can use their home during larger periods of time and in ways more adequate to variations of seasonal climate. These strategies of physical flexibility can eventually be replaced by policies of interchangeable housing units according to phases of familiar life-cycles, even that such task nowadays faces the problem of the absence of linearity on the stages of familiar life.

3.6 *Health and Comfort*

Until now we have being pointing out biophysical aspects from housing related to the main natural resources: soil, energy, water, waste, materials and space. However, there remain no doubts that the idea of relating housing production to this environmental resources results from the need of improving mankind quality of life on long term. In this sense, sustainable buildings and residential areas to offer quality of life must provide permanent conditions of comfort and health to its inhabitants. Assuring housing quality is then an aim of sustainability, which can be achieved through the following strategies:

a) To assure interior environmental quality (IEQ): Toxical substances, VOCs, dust and radiations are the main contaminants of interior environment. Further than controlling the presence of such substances, ventilation is the way to avoid higher concentrations and eventual risk situations. Security, salubrity, comfort, relation with the exterior, sky visibility and tranquillity are the main requisites of a healthy interior. Comfort, however, is the most complex requisite and its evaluation demands parameters of air and surfaces temperature, moisture, air velocity, noise, light and smell, adaptable to personal relativity.

b) To minimize consumption while maximizing comfort: Although Western ways of life show the opposite, comfort conditions should be achieved with a minimum consumption of non renewable resources and with an appropriate management of renewable and local resources. Extensive use of air-conditioning and extensive irrigation of gardens with drinkable water, are clear examples of wrong attitudes. However, with the increasing environmental conscience, inhabitants start to get aware of collective and individual advantages of alternative ways to obtain desired levels of comfort.

3.7 *Adaptability and Identity*

On the last decades ways of life have suffered mutations produced by several social factors. The improvement of living conditions, the diversification of forms of co-housing, the increase of divorce rates, the "informatization" of daily life and the spreading of new ethical values transformed contemporary housing needs.

Sustainable housing aims to satisfy needs on long term, for it should be adaptive to contemporary ways of life and responsive to inhabitants' desires and to their changes on time. Conventional housing models should be reviewed, and flexibility should be one way to respond to increasing diversity of the population needs, as to its accelerated rhythm of change.

Adaptability increases inhabitants' appropriation of their neighbourhoods and houses, which can also be encouraged through the availability of collective spaces, elements of self identification, and through processes of public participation on the decisions about planning and managing the neighbourhood. This challenge demands the creation of a strong identity, on the neighbourhood as on the region.

Identity can be reinforced by housing quality and adaptability but also with collective infrastructures, starting with planning of transport nets and new mobility strategies (car sharing or car pooling, for example), integration of communitarian urban agriculture, and arriving to the implementation of centralized or generalized passive and active systems of renewable energy (as co-generation or solar or wind energy generation) that can work as community symbols.

4 AT WHAT SCALES ARE MAIN DECISIONS TAKEN?

In order to promote housing sustainability the above listed guidelines should be taken into account in three main scales of decision: urban, architectonic, and construction.

4.1 *Urban scale: density and territorial integration*

Housing is not only a matter of buildings but also an important part of the territorial system and of the social community. Thinking on these scales allows understanding the resources supply, as well as how residential areas and their housing units are used.

Housing is a form of urbanization that brings human pressure to a certain land, according to its settlement size, density, soil permeability, nets of transport and mobility, and also from the relationship established with agriculture and food supply. Density of land urban use assumes a critical role on the environmental impacts of urbanization because it interferes on the efficiency of natural resources use and on the mobility model.

However, low density developments are increasing, although implying high use of land and infrastructure. This happens due to the demand of wealthy urban families for bigger houses and green spaces, and in reply to the needs of semi-rural societies.

Density is a major problem of housing production, deeply related to territory management but also with the success of residential areas and with its urbanity. Density, as numeric rate between housing units and land area, should not be confused with the compacity as propriety from urban form. Compact cities, as defended for several authors, can exist in urban uses of soil with quite different densities, and with more or less sustainable relations with the territory that supplies them.

Increase of density is a strategy for neighbourhoods regeneration, because it allows to profit from infrastructured soil. To increase density the number of housing units for land unit can be increased, or the size of the houses can be enlarged (keeping the same number of units).

4.2 *Architectonic scale: morphology, orientation and typology*

Although it is proved for long that buildings with North - South orientation achieve the best energy performance, the practice shows that buildings with other orientations can have economic and urban advantages, and that to produce sustainable housing doesn't mean to build always exclusively North-South.

The model of the classical urban block delimitated by four streets implies buildings with different orientations, being impossible to assure that all the apartments have theoretically an optimal energetic performance. However, this urban morphology is considered one of the more permanent and sustainable ones with advantages of flexibility, adaptability and efficiency on the creation of urban complexity and coherence. The right orientation of a building depends on a group of interrelated strategies that allow it achieving high rates of thermal, visual and lighting comfort. In reality, if orientation would be an exclusive guideline of urban morphology, cities would go back to the Athens Chart Model, whose debilities are largely demonstrated. Such examples are being produced nowadays, where solar efficiency is elected as the main objective of architecture neglecting the needs of urban coherence, diversity and public space quality.

At the same time, orientation East-West, in general with worst energetic performance, shows also advantages, allowing designing flats with more natural light (morning and afternoon). About this last solution it has, however, to be said that mono orientated flats neglect the importance of cross ventilation, demanding higher consumption of energy for cooling and control of indoor air quality and of lighting conditions.

4.3 *Constructive scale: construction systems and technology*

Planning housing production, further than decisions on density or on morphology, requires electing the right construction system for a certain housing demand. As known, construction systems according to their materials and processes can have very different environmental performances. In one hand the materials used incorporate directly certain consumption of resources, and on the other hand, they interfere on the energy demand of the building and of its spatial use.

There are two typical constructive systems on the production of housing, which are: the concrete structured and brick filled with generous surfaces of glass ("conventional heavy weight system"); and, the wood structure and panel filled with reduced surfaces of glass ("experimental light weight system"). On the first system thermal mass is more important and the second the focus is on thermal insulation.

The light weight system is frequently pointed out as the system for the future, mostly from the high-tech side and from the defenders of housing prefabrication. The heavy system by its turn is pointed as the ideal for solar energy conservation due to its higher thermal inertia. Neither one, nor the other is universally ideal, and a compromise should be made between the two combining insulation and mass according to climate, seasonal uses, materials and resources available.

Sustainable housing construction systems should allow an optimized use of solar gains. Orientation, at the scale of architectonic decision, has a role on achieving this objective, but also materials used on construction systems, and the relation between transparent and opaque walls, determine hit balance, energetic needs, and so sustainability from the building stock. Finally it should be said that appropriate technology has a role on housing sustainability at the construction level. High technology used in other industries can have punctual benefits on housing environmental performance but low technology, with its reduced resources use, and profiting from traditional knowledge, can in certain contexts respond to housing demand in an efficient way.

5 WHAT IS THE CONTRIBUTION OF HOUSING REHABILITATION?

Construction of new housing is no longer a political priority, since recent statistics showed that in Portugal there are already more houses than families. Importance of housing rehabilitation will certainly increase in the future, so it is important to analyse its contribution to sustainability.

Rehabilitation of residential buildings, ancient or recent, constitutes a privileged way to achieve sustainability objectives, having advantages from the environmental, social and economical points of view.

As an alternative to construction of new buildings, rehabilitation interventions prevent the occupation of more soil and unnecessary use of more energy and materials. In addition, it increases the working service life of existing buildings, and so the rentability of the resources already applied. Housing rehabilitation also contributes for social cohesion, since it improves dwellings and urban spaces quality, strengthens user's identity by preserving the community cultural and built heritage, and contributes to reduction of social asymmetries. Finally, housing rehabilitation helps to preserve cultural and building heritage of cities, which are crucial factors for their vitality, contributing for their economic performance and competitiveness.

However it is important to remember that housing rehabilitation also constitutes a crucial opportunity to integrate some of the above mentioned guidelines in order to improve its performance. For example, a rehabilitation operation may be used to improve comfort conditions by reinforcing the thermal insulation, assure a healthy environment by removing hazards materials, integrate energy efficient equipments, diversify dwellings size and internal organization of spaces, and guarantee accessibility to all users.

6 FINAL REMARKS

1. During recent years housing was produced to answer the short term needs of a consumerist society, compromising the future of residential areas, cities and regions. However, the development of more sustainable ways of living, assuring the optimization of natural resources use and the satisfaction of housing needs, seems to be finally recognized as an important collective objective to fulfil.

2. Sustainable architecture started as a utopia and originated a vanguard, but currently it is starting to be a fashion adopted by the real estate market. If we are optimist we can argue that ecology ethics reached public opinion. But, if we are pessimists, we can argue that sustainability is condemned to a superficial approach, with negligible environmental and social benefits.

3. It is widely spread the idea of “green architecture”, which is not necessarily architecture with good environmental performance. This stereotype is associated with images of great visual strength, such as buildings surrounded by vegetation, semi-buried, with large glasses and green roofs. This “green” stereotype gained a strong visibility in mass media and due to it sustainable buildings became a popular tendency. But this quick popularization also brings the danger of rejection, if sustainable buildings are simply understood as a fashion experience. It is important to underline that the environmental sustainability of a building lays on its performance and does not have necessarily an architectonic expression.

4. The awareness of public opinion about sustainability problems is increasing. However, as individuals, most people seek for better living conditions and short term satisfaction. To solve the apparent contraction between environmental consciousness and life quality we deposit an almost unshakeable faith in technological progress. It is important to bear in mind that technology may help reaching some of the sustainability objectives by developing new materials and systems. However there are no technological miracles. To reach more sustainable solutions changes in the way we build and use housing are necessary.

5. The application of the above mentioned guidelines in Portuguese housing developments is no longer a distant utopia. There are few examples of new housing developments, some of low cost, that successfully apply many of those guidelines. Scientific and technical expertise already exists, being now necessary to move from exception to rule. Incorporating strategies of sustainability into housing construction and rehabilitation proved to have two advantages: not only does it have a significant contribution to the achievement of sustainable development objectives, but it will also provide important advances in housing quality, durability and cost effectiveness.

REFERENCES

Mourão J. ; Pedro, J. 2005. Sustentabilidade da habitação e das áreas residenciais. Lisboa: LNEC.

The impacts of residential buildings – How to identify life cycle based improvement potentials

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ABSTRACT: The environmental performance of new and existing buildings can best be improved by respecting the life cycle perspective. Conducting a Life Cycle Assessment efficiently supports the identification of environmental improvement potentials.
The research project "Environmental Improvement Potentials for Residential Buildings" (IMPRO-Building) was initiated by the European Commission (JRC-IPTS). It aims at reducing the environmental impacts from residential dwellings throughout their life cycle, evaluating the current situation of residential buildings in the EU-25, before analyzing improvement options.
A generic life cycle model for buildings has been developed to address this question efficiently. It is used to identify the environmental hotspots and to evaluate improvement options. More than 70 building types are assessed consistently. The LCA model makes a distinction between existing (use phase and end-of-life) and planned buildings (construction phase included as well), accounting for different perspectives.
Results are demonstrated for examples of different building types from different geographical zones.

1 RESIDENTIAL BUILDINGS IN THE EU-25

A synopsis of residential buildings throughout Europe provides the adequate basis for investigating the impacts of residential dwellings and for identifying environmental improvement options. This synopsis has to be laid out in a way that it can be directly adopted to model the life cycles of residential buildings.

A first division into 'single-, two-family-, and terrace-houses', 'multi-family-houses' and 'high-rise buildings' is used to allow for the individual buildings to be ordered according to their architectural design and to constructional and material criteria into building types. This ordering is conducted within three geographical zones, namely north-, middle- and south- European countries, and yields a total of 73 individual building types, of which 54 types represent existing buildings and 19 types represent newly constructed buildings. These 73 building types cover more than 80 % of all residential buildings in the EU-25. The geographical zones are assembled from EU-25 member-countries on the basis of average heating degree days per year.

This overview of European residential buildings is based on comprehensive databases containing technical information of buildings for an extensive building stock throughout Europe. These databases have been set up to analyze the technical state of the European building stock.

2 ANALYSIS OF LIFE CYCLE-BASED ENVIRONMENTAL HOTSPOTS OF RESIDENTIAL BUILDINGS

The extensive basis of 73 residential building types to perform life cycle assessments, addressing the impacts of residential buildings as well as the challenging task of identifying environmental improvement options from a European perspective, demands for consistency and mechanisms to automate certain procedures when modeling the life cycle of buildings.

To meet these challenges, a generic building model, providing a common structure for all individual building types, has been developed. Within its common building structure, this generic model contains all relevant construction materials that are found in either of the building types to be modeled. Parameters are extensively used to define the actual life cycle model and to efficiently adjust the generic model to fit to the respective building type.

The life cycle model divides into two distinct model versions. One represents the life cycle of an existing building, where the construction phase is not considered, but the use phase and the end of life (see Figure 1). The second version represents new buildings, where the construction phase is also incorporated into the building's life cycle (see Figure 2). This distinction into two model versions supports the identification of the decisions that can be made today. Promoting retrofit measures with existing buildings, for instance, presents a feasible decision to be made, while past construction actions do not provide space for any improvement today. Consequently, the construction phase is not considered for existing buildings. It is, however, important to consider the structure and the materials used for construction, in order to be able to give statements considering retrofit options and to be able to account for the building's demolition.

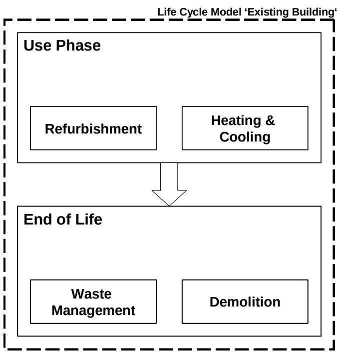

Figure 1. System boundaries and considered life cycle phases for existing buildings.

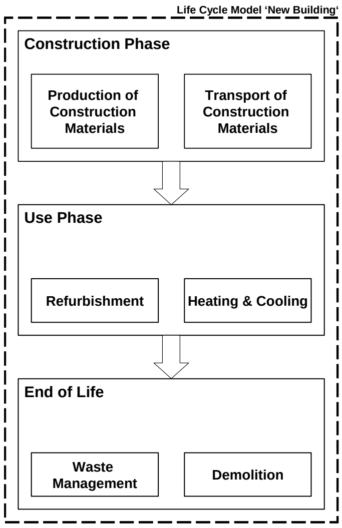

Figure 2. System boundaries and considered life cycle phases for new buildings.

The generic model, and consequently the individual building type models, bear a common structure of construction elements that assemble the required building materials of the respective part of the building. These construction elements are the roof, the exterior walls, the interior walls, the floors and ceilings, the windows and finally the basement. The life cycle phase of the construction of new buildings considers the construction materials used, as well as the transportation of the materials on the level of the construction elements of the building.

Following the objective of the study of investigating improvement options for residential buildings that are based on decisions considering the selection of constructional alternatives or constructional practices to be encouraged, the construction materials stand for European average datasets. The use of such European datasets that represent average technology data for the manufacturing of construction materials and European boundary conditions, assures that derivations in background data do not bias the basis for the decisions to be made within the scope of the study.

Within the use phase, two major aspects of the utilization of a building are considered. These are, on the one hand, refurbishment actions that are conducted to maintain the function of the building, in general without changing the energy performance of the building. While retrofit measures describe actions that are taken with the aim to improve the performance of the building, it is known that some retrofit actions are taken in conjunction with refurbishment actions that have to be conducted in order to maintain the buildings' function. An example of such retrofit actions that go in line with refurbishment actions are the regular exchange of windows, where the existing windows are replaced with 'modern' windows that reduced heat transmission values. Another example is the insulation of the roof at a point, when the battening and the tiles have to be replaced. These measures are handled as refurbishment, in order not to overestimate certain retrofit actions as improvement options.

On the other hand, the heating energy demand, as well as the cooling energy demand, which is believed to gain significance in the future, is considered. Within the model, the heating energy demand is calculated from the energy balance that is based on heat transmission coefficients for the individual construction elements of the building type. The cooling energy demand, on the other hand, is provided as average values for each geographical zone, thus incorporating the fact that most indoor cooling devices within residential buildings work on a per-room basis. This means that the use of indoor cooling equipment in different building types does not generally differ.

The end-of-life phase of the models considers both, wastes from the demolition of the entire building, as well as wastes from the exchange of materials due to refurbishment actions. Recycling rates, shares for the deposition onto inert materials landfills, as well as incineration and other end of life routes are considered on the basis of average data for the construction sector throughout Europe.

One objective of the study is to provide information upon which recommendations for favorable actions, related to the improvement of the overall environmental performance of residential buildings may be given. Therefore, a maximum timeframe for the life cycle assessment of 40 years has been chosen. While this does not implicate that all buildings are expected to be demolished no later than 40 years from now, it is believed that no statement upon the development of the residential building sector beyond these 40 years can be made.

For both, existing, as well as new buildings, the impact assessment of the life cycle models is conducted and environmental hotspots within each building type need to be identified. The impact assessment is conducted using the CML 2001 characterization model (CML 2001) and the considered environmental indicators are the use of fossil primary energy, the use of renewable primary energy, as well as the impact categories 'global warming potential' (GWP_{100}), 'acidification potential' (AP), 'eutrophication potential' (EP), 'photochemical oxidant formation potential' (POCP) and 'ozone layer depletion potential' (ODP). These environmental indicators describe environmental effects that are, among others, generally considered as relevant within the current environmental discussions (JOLLIET ET AL. 2003).

3 LIFE CYCLE IMPACT ASSESSMENT OF THREE EXEMPLARY BUILDING TYPES

The life cycle impact assessment (LCIA) of three building types is displayed in order to demonstrate the outcome of the analysis of the current situation of residential buildings in Europe. Those examples are:

– A ten-storey high-rise building type (concrete-based structure) from the south of Europe that has been built in the 1970s and is expected to be in use for another 20 years,
– A single-family building type with a brick masonry structure from central Europe that has typically been built between the 1940s and 1980s and that is expected to used for at least another 40 years, and
– A four-storey multi-family building type with an insulated brick masonry structure from the north of Europe that is planned to be built in the near future and on the basis of the current construction practice.

For the comparison of different building types, as well as of different construction elements within one building type, the results of the LCIA are presented on a per-square-metre-and-year-basis.

Figure 3 illustrates the contribution from different life cycle phases to the global warming potentials of the described building types. As described above, neither the high-rise building (left), nor the single family building (centre) contain a construction phase, as they represent existing buildings. The multi-family building (right), on the other hand, includes a construction phase. From Figure 3 it is clear that the heating and cooling energy consumption has the by far greatest impact on the building's life cycle. The construction phase, as well as the refurbishment measures taken and the end-of-life, on the contrary have rather minor impacts on the GWP_{100}. The 'incorporated GWP', having negative values, is in part due to wood, which is, in some sections of residential buildings, extensively used as a construction material. Another source for incorporated GWP is the use of renewable materials as fuel in residential heating. Consequently, the net value of the GWP_{100} is clearly below the currently displayed values.

From this graph (Figure 3), it can be stated that these building types, especially the single-family building type and the multi-family building type do not represent current best practice in construction, where the energy consumption for heating were significantly lower. For existing buildings, taking refurbishment measures usually reduces heat losses significantly. The reductions in heating energy losses due to refurbishment actions are considered in the displayed figure.

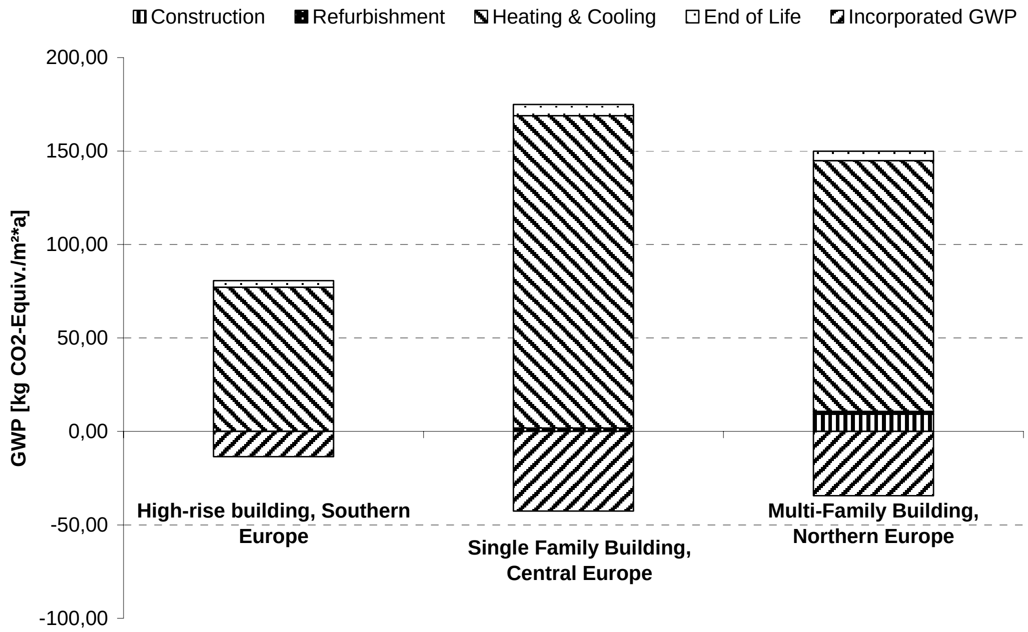

Figure 3. LCIA results for the global warming potential from the life cycles from three residential building types throughout Europe. Displayed: contribution from different life cycle phases to GWP_{100} in kg CO_2-Equivalent/(m²*a).

Following the objective of the study to identify environmental improvement options, the individual building types are evaluated in a way that identifies the life cycle impacts from individual construction elements. Figure 4 displays the contributions from all construction elements to the global warming potential for the above described multi-family house from northern Europe. Some types of energy losses may not be allocated to individual construction elements within the context of an entire building and are presented separately.

From the graph in Figure 4, the impact from the manufacturing and demolition of construction elements, especially of those with high masses can be identified. The major impacts, however originate in ventilation, which stands for energy losses due to leaking window- and door-frames and other structural weak points. While the effects of ventilation may not be directly allocated to the windows, the heating losses of ventilation may be reduced by choosing adequate window types. Other highly significant impacts originate in losses from the heating system. These losses are directly related to the overall energy consumption of the building.

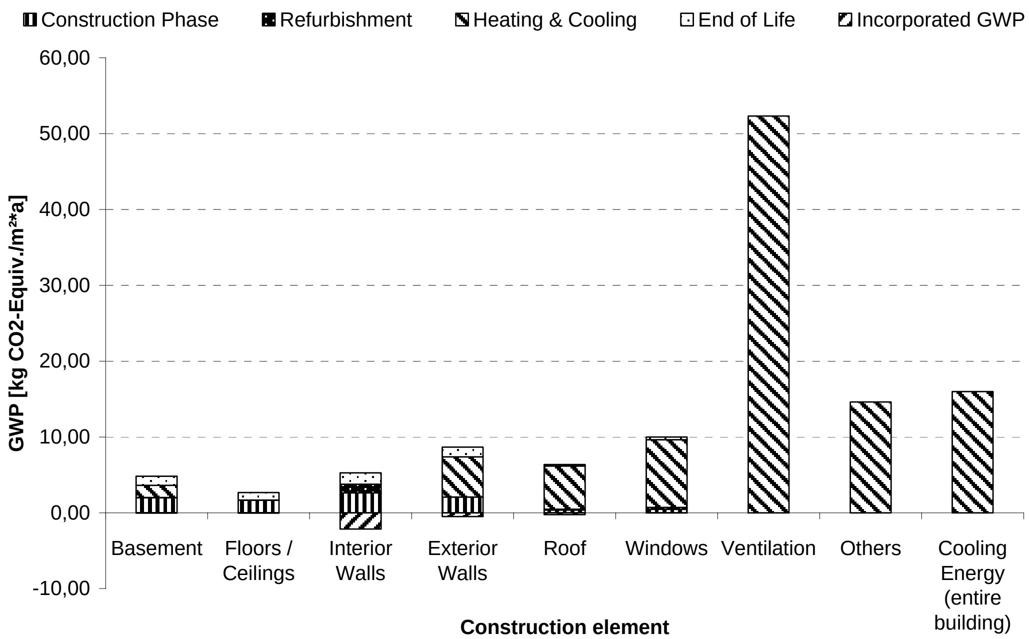

Figure 4. Contributions from construction elements and energy consumption to the global warming potential of the above described multi-family building type (North Europe). Note that the energy consumption from 'ventilation', 'others' and 'cooling energy' may not be allocated to individual construction elements and are therefore presented separately. Displayed: contribution from construction elements to GWP_{100} in kg CO_2-Equiv./(m²*a).

4 CONCLUSIONS

Choosing the approach of developing a generic, parameterized building model that has been specifically designed to incorporate the relevant aspects of residential building practice in Europe, proved to be a demanding, yet viable way to approach the task of addressing the environmental impacts of residential buildings. Aiming at evaluating residential buildings throughout 25 European countries, the clustering into 73 building types and a consistent set of background data is an essential precondition for the approach chosen.

The results of the life cycle impact assessment of three exemplary building types show clearly that the use phase is the predominant life cycle phase for residential buildings and that special attention needs to be addressed to the reduction of losses of heating and cooling energy. Especially the high environmental impacts from the consumption of cooling energy directs attention to an issue that is believed to gain significance in the future as indoor cooling devices will become more available and will be more often used. As the protection from heat can not be accomplished with the same means as protection from cold, strategies and materials specifically designed for serving as summerly heat protection may provide feasible means for improving the environmental performance of the building.

For at least some of the analyzed building types, losses of heating energy due to ventilation appear to be a major aspect to be addressed in the future. In general, the study shows clearly that options to improve the environmental situation of residential dwellings in Europe exist and that adequate measures can be and have to be taken.

REFERENCES

CML (2001): CML's impact assessment methods and characterisation factors. Leiden University, Institute of Environmental Science (CML). Online: URL: http://www.leidenuniv.nl/cml/ssp/databases/cmlia/

JOLLIET, O. ET AL. (2003): Final report of the LCIA Definition study. Life Cycle Impact Assessment Programme of the Life Cycle Initiative. Lausanne, Switzerland.

The contribution of the National Laboratory of Civil Engineering (LNEC) to a sustainable built environment

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ABSTRACT: As a research and development institution, integrated in the Portuguese National System of Science and Technology, the National Laboratory of Civil Engineering (LNEC) is well positioned and fitted with human and material resources to develop studies and other actions towards the improvement of construction sustainability.

The multiple skills in diversified scientific areas (engineering, physics, chemistry, geology, architecture, urbanism, social sciences) of LNEC researchers are particularly suitable to the interdisciplinary and multidisciplinary approach required by environmental sustainability matters. Besides a brief reference to past pioneering studies on this area, the paper describes LNEC present and future research lines on sustainable construction. These research lines include studies carried out on several transversal themes such as environment and sustainability, conservation and rehabilitation, quality in construction, human and social-economic dimensions, and risk and safety. To conclude, some final remarks are presented.

1 INTRODUCTION

It is well known that the construction sector represents one of the largest and most significant driving forces in fast-growing economies. The activity of this sector traditionally led to the extraction, transformation and use of massive amounts of material resources, as a response to the increasing demand for higher quality of life standards, namely in its different aspects related to housing, working environment and urban areas. Looking at another reality, the continuous growing of urban areas' population (migrant and immigrant) created unbalanced and degraded urban settlements where basic needs and minimum quality of life are not assured to all citizens. There is an understanding and acceptance of the pressing need to question the basis of the "growing as usual" social, economical and environmental scenarios. In the built environment, as in all other society "environments", inflecting and, if necessary, correcting the way environmental, social and economic issues are dealt with, or have been inherited, is a recognized task for the present and future generations.

In view of this reality, sustainability quickly became a dominant issue and keyword, although the effective shift from theory to reality may in many aspects be questionable.

As a research and development institution integrated in the Portuguese National System of Science and Technology, LNEC has revealed to be well positioned and fitted with human resources and physical infrastructures to develop studies and other actions that may support the improvement of the country's situation, quite unsatisfactory regarding sustainable construction.

Multiple skills in diversified scientific areas – engineering (civil, mechanical, chemical, electronics and computer), physics and technological physics, chemistry, geology, architecture, urban planning, environment, social sciences (sociology, social and environmental psychology, anthropology, geography) – are particularly suitable to the multidisciplinary and interdisciplinary approach required by sustainability matters.

The many activities described herewith comprise programmed and contracted research; technical assessment of traditional and innovative solutions; and dissemination of technical, scientific and practical knowledge.

LNEC`s programmed research related to construction sustainability is located in several projects and studies connected with five transversal domains: *Environment and Sustainability*, *Conservation and Rehabilitation*, *Quality in Construction*, *Human and Social-economic Dimensions*, and *Risk and Safety*. These projects and studies are developed in different LNEC departments and divisions; several of them are co-financed by external grants and are being carried out in partnership with other institutions. A significant number of research studies are also supporting MSc and PhD theses, undertaken by either in-house assistant researchers or fellowship researchers. Research by contract, technical assessment and dissemination of knowledge is usually requested by public and private entities including industry.

In the following sections are present some of the most relevant areas of LNEC past and present involvement for improving the construction and urban environment sustainability. Reference is also made to LNEC commitment to future actions on the field.

2 MATERIALS, PRODUCTS AND SYSTEMS

The assessment of sustainable building materials, products and systems should focus on environmental, economic and social aspects, putting the accent on the corresponding environmental impacts, but their global performance, including durability, should not be overlooked.

LNEC has a long tradition of technical assessment and qualification of building products and systems, being a member of the European Union for Agrément (UEAtc) and the European Organisation for Technical Approvals (EOTA). For many years LNEC has been the Portuguese reference technical assessment body, issuing technical agréments ("documentos de homologação") for building products, components and systems. The range includes, just to name a few, prefabricated structural floor systems, masonry units, window systems, wall, ceiling and floor coverings and finishes, roofing coverings, roof waterproofing systems, thermal insulation products and systems (such as ETICS and inverted roof systems) and plastic water supply and drainage piping systems. All these products, components and systems, in one way or the other, have an important role to play in building sustainability.

Besides the current technical assessment activities, researchers of different Departments of LNEC have been involved in programmed research and research by contract (Santos 1994, Nunes et al. 2004, Moita et al. 2005, Esteves et al. 2006, Gonçalves et al. 2006, Martins et al. 2006, Velosa et al. 2007, Vieira et al. 2007) concerning the characterization, improvement, technical viability or end-use performance of natural materials, industrial waste and by-products and demolition materials. Natural and recycled wood and cork, coconut and plastic fibres, sheep's wool, plastics, autoclaved aerated concrete, ceramics and stone resulting from demolition and industrial waste, are only a few examples of such materials. It should be recognized that there is still a great potential, demand and need for environmental conscious interventions in this area, requiring support and incentives at technical, industrial, financial and consumer level.

The next (ongoing) step is to complement the technical assessment currently carried out with an environmental approach, which will supply relevant, technically robust and non-ambiguous information to consumers. A whole life evaluation of building products and systems is required in order to attain a complete and meaningful sustainable evaluation of buildings. This is a complex and demanding task. A reliable, comprehensive and updated amount of information will be needed in the near future. Besides the use of LNEC expertise, research and experimental capacities (mainly embedded in three departments: Building, Materials and Structures Departments), it is necessary to have the fair and participative collaboration and support from all those involved: raw materials suppliers, manufacturers and their associations; building promoters, builders and owners; building services and maintenance managers; and central and local authorities. To enable and to profit from LNEC multidisciplinary capacities, a stronger collaboration with all these entities is sought, namely through partnerships in co-financed research projects.

As a first step forward, it is intended to introduce gradually in LNEC technical agréments the environmental qualification of building products, components and systems. More detailed life cycle assessment (LCA) data and methods are needed and will be developed. Glazing/window systems, prefabricated structural floor systems and thermal insulation products have been targeted as priority issues.

Other important related areas of interest will be addressed at a further stage:

– Sustainable site management, comprising not only materials and products waste reduction, but also the rational use of energy and water, and pollution control;
– Required skills (teaching and qualification of technicians and workers) and improvement of workmanship quality.

3 ENERGY EFFICIENCY AND INDOOR ENVIRONMENTAL QUALITY

Meeting the needs of people and providing quality of life and work are closely related to an healthy and comfortable indoor environments. Sustainable development requires that this target should be reached with minimum acceptable energy impacts.

LNEC has pioneered in Portugal the study and practical implementation of such matters as building's energy efficiency and indoor environmental quality (thermal, acoustical and visual comfort, air quality).

As far as 1979 LNEC established thermal performance requirements for school buildings (LNEC 1979) which preceded the first Portuguese thermal regulations (issued in 1990).

More recently, LNEC actively participated in the drafting of the new 2006 Portuguese building thermal regulations and energy certification scheme, and proposed the creation of a *Surveillance and Revision Committee*. This committee would be able, on the one hand, to detect and propose, in due time, solutions for major problems which may hinder and jeopardize the application of the regulations and, on the other hand, to influence in a sustainable way the future revision of the present regulations within an expected five years period. The need for such committee is becoming more and more evident as the application of the mentioned regulations proceeds.

Understanding, applying and practicing sustainability, whatever the field of activity, require competent technicians and experts. The correct application of new regulations, either at design or execution stages, demands adequate dissemination of knowledge and training of designers, experts and technical managers. For several decades LNEC organizes specialized training courses and technical knowledge dissemination. Time allocated and technical expertise, appealing to the collaboration of external experts if necessary, is a key factor in the LNEC involvement in this field. From January to June 2007 LNEC organized comprehensive courses on technical dissemination and practical application of the new thermal regulations. It is intended the recognition of these training courses as a technical basis for the qualification of experts required for the application of the energy certification scheme derived from the implementation in Portugal of the European Directive on Energy Performance of Buildings.

Indoor environmental quality – from the thermal, visual, air quality and acoustical points of view – and energy related impact issues have, since long, been areas where LNEC develops research activities of experimental nature (Matias et al. 2006; Santos 2002, 2006; Pinto 2006). In 2007 several PhD theses are under way: development of climate, social and economically concerned adaptive thermal comfort approach based on field research (*Development of an adaptive thermal comfort model adapted to Portuguese conditions,* ongoing PhD thesis*)*; day lighting and sustainability in Southern Europe *(Energy impacts of natural day lighting of buildings,* ongoing PhD thesis); influential parameters on indoor air quality (*Buildings indoor environment quality,* ongoing PhD thesis). In the acoustics field research and experimental work is being extended to the outdoor environment, focusing on the integration of qualitative aspects of the acoustic environment of urban spaces (*Acoustic environment assessment in urban areas. Integration of qualitative aspects,* ongoing PhD thesis). The results of these research works will be hopefully integrated in guidelines promoting and supporting a sustainability-oriented approach.

Many new and existing Portuguese buildings show weaknesses to face what is typically a Southern Europe problem (but is also becoming a Northern Europe one): summer and mid season overheating. This situation is already partly responsible for the noticeable increase of energy consuming air conditioning equipment installed in the residential sector. Poor flat and pitched roof thermal "protection" (solar reflectance, thermal insulation and ventilation) and, more recently, poor windows characteristics (significant glazed area and inappropriate solar protection) are responsible for unacceptably high indoor temperatures. In the near future a significant decrease in the Portuguese buildings traditional high thermal mass may also be predicted, due to a perceived tendency for lightweight constructive solutions namely in internal partitions and linings, application of internal thermal insulation, and internal wall and ceiling finishings with acoustic properties and moderate thermal resistance.

LNEC contribution on this field covers the establishment of better criteria for assessing and characterizing external glazing (Pinto 1997), sun-shading devices and roof solar "protection" alternatives (Matias 2001) post-occupancy evaluation, dissemination of good practice and re-evaluation of thermal regulation requirements.

Another important area of research, technical assessment and dissemination is strongly emerging. With the new building energy efficiency regulations, the use of thermal solar collectors has become mandatory for many new buildings. Barriers to the implementation of this measure are related to integration aspects, performance reliability and durability. Besides thermal solar collectors, microgeneration systems integrated in new buildings should be promoted and best solutions and practices should be identified and monitored.

A greater challenge will be the integration of these renewable energy technologies in existing buildings, which by far represent the largest part of the built environment. Reasonable and viable solutions and options should be studied, supported and disseminated.

For the future the forefront of LNEC work program will continue to emphasize energy efficiency and indoor environmental quality aspects. The following issues are considered of high priority:

– Summer cooling loads minimization through solar radiation protection strategies, and integration of thermal capacity to counterbalance the increase of lightweight construction methods;
– Green roofs impact on solar loads;
– Advanced day lighting and artificial lighting solutions and respective impacts;
– Natural and hybrid ventilation, indoor comfort, outdoor noise and air pollution;
– Double skin façades;
– Integration of microgeneration technologies in buildings.

4 WATER USE IN URBAN AREAS AND BUILDINGS

LNEC activity on the efficient use of water in urban areas and buildings is centered in the Hydraulics and Environment Department, whose researchers participate in many different research and good practice dissemination projects (Almeida et al. 2006).

The efficient use of water in buildings will continue to be a key subject in building sustainability research and dissemination activities. The following areas will deserve special attention in the near future:

– Characterization and qualification of fixed water appliances;
– Feasibility and options for rainwater recovery and use;
– Rainwater surface flow reduction through the use of good design and maintenance of green roofs and porous urban surfaces.

5 BUILDING MAINTENANCE AND REHABILITATION

Maintenance and rehabilitation issues are closely related to sustainability concerns of rational use of existing built resources, the preservation and identity of present and future cultural heritage, energy efficiency and reduction of energy consumption, quality of life and well being of the users.

Materials degradation and durability, service life, performance analysis, maintenance and rehabilitation issues (Veiga et al. 2004) are responsible for a significant and wide spectrum of diversified research and dissemination activities carried out at LNEC for many years.

These activities embrace the appraisal of the state of conservation, and the contribution to better maintenance and rehabilitation interventions, not only of today's built heritage, but also of the recent built environment (tomorrow's built heritage).

Just to refer a few major LNEC research lines or collaborations within this extensive scope:

- Diagnostic procedures and methodologies for evaluating the degradation processes and improving rehabilitation interventions (*Study of degradation processes of wall renders of ancient buildings in Portugal*, ongoing PhD thesis; *Development of methodologies for the assessment of moisture effects in old buildings*, ongoing co-financed research project; *Characterization and conservation of traditional historical mortars from Alentejo´s religious buildings*, ongoing co-financed research project);
- Study of materials processes and techniques for repairing and rehabilitating existing buildings (*Conservation of lime mortar renders. Improvement of architectural rehabilitation techniques and materials*, ongoing co-financed research project);
- Building maintenance strategies and activities (*Managing maintenance activities in public buildings*, ongoing PhD thesis);
- Integration of advanced IT in existing buildings (*Housing and information society. Study on the integration of information and communication technologies in the existing housing stock,* ongoing PhD thesis);
- Development of an evaluation method (Pedro et al. 2006) of the state of conservation of buildings, applied in the framework of the new Portuguese urban renting law. Following the development of this evaluation method and its official implementation, LNEC is preparing training courses for future recognized auditors and is initiating the development of complementary tools for the definition of rehabilitation strategies *(Evaluation method of buildings' state of conservation. Contributes for the method improvement and extension,* ongoing PhD thesis).

A good example demonstrating the accumulated experience and expertise in this field is the recent comprehensive *Housing Rehabilitation Technical Guide* (Paiva et al. 2006) produced and issued by LNEC on behalf of the National Housing Institute (INH).

Thermal quality and rehabilitation of the building envelope has also deserved a special attention for many years. It is foreseen that it will have a major part to play in LNEC's research and dissemination activities in the near future. Social and economical evolution (well being expectations, changing market trends) and sustainability concerns (energy efficiency, energy certification, user dictated upgrading needs of existing building stock) will require sound basic data and expertise knowledge in order to enable the definition and assessment of the best economic and technically viable options.

6 URBAN SUSTAINABILITY

To achieve a more sustainable built environment, decisive changes should happen, not only at the building level, but also at urban scale. It is important to catalyze the public opinion momentum toward alternative or more coherent strategies, based upon sustainable development principles that improve the quality of life and competitiveness of cities and urban regions.

Taking account of this priority, an intensive research activity has been developed at LNEC in recent years, aiming at contributing to a broad understanding of urban sustainability. The studies covered some major areas within this subject:

- Urban design: public spaces of residential areas (Coelho 1992), quality program for residential areas (Pedro 1999);
- Environmental quality: setting up of climatic principles in urban planning (research project in co-operation with the Centro de Estudos Geográficos of the University of Lisbon);
- Social aspects of the urban environment: empowerment processes regarding relational conflicts management (Freitas, 2001), uses and appropriation of urban space (Menezes, 2003), ageing and old age in the urban environment (Machado, 2005), environmental conflicts related to land occupation (Craveiro, 2006);
- Transport, sustainable development and quality of life: transport related environmental externalities and estimation of environmental values for use in road pricing and cost-benefit analysis of transport and mobility plans, policies and programmes; use of revealed and stated

preference data collected in Lisbon and discrete choice modelling (Arsenio 2002; Arsenio et al. 2006);
- Patterns of human coping with environmental extremes: public risk perception of populations at risk (Lima et al. 1991, Silva 1996), patterns of integration of low probability, high catastrophic risks in land-use management and governance (Silva 2006);

Other research studies are at present under way, namely: a systematic analysis of the patterns of integration of risk mitigation and emergency preparedness on land-use policies and governance, aiming at conceiving a tool to support practioners in their periodical assessment of achievements concerning risk management (*Risk management and governance*, ongoing PhD thesis); a state of the art on urban rehabilitation and evaluation of the local technical cabinets experience (*The activity of the local technical cabinets in urban rehabilitation. Analysis, diagnosis and methodological contributes to an integrated intervention in historic areas*, ongoing PhD thesis); the development of a qualitative analysis method of urban environment sustainability (*Urban morphology and metabolism. New strategies of urban ecology to minimize collective costs of contemporary Portuguese city*, ongoing PhD thesis); a state-of-the-art on the social costs of transport, including road/rail/air/cycling/other modes; sustainable mobility focusing in greener transport for urban areas and planning for sustainable land use and transport (ongoing research studies at the Transportation Department, within the scope of LNEC programmed research plan).

For the near future, LNEC considers a priority to develop studies integrating different fields of knowledge and to have results oriented for practical application. The following subjects emerge as promising:
- Development of indicators to evaluate the urban environmental sustainability;
- Establishment of guidelines for sustainable housing neighbourhoods design, considering environmental, social and economic perspectives;
- Development of a procedure for more effective consideration of safety issues in the decision making process of urban transportation networks, especially concerning the road infrastructure maintenance and putting a special emphasis on vulnerable road users' safety.

7 CONSTRUCTION AND SOCIAL CHANGE

Society is in a permanent and fast transformation stimulated by several factors among which the social change. Population growth, population ageing, migrations increase, social and ethnic diversification, new forms of family aggregation, reduction of family dimension, longer and more varied life cycles, segmentation of the homogeneity in ways of life, weakening of the collective values, are all signs of that social change.

Social change should be understood as an expected condition of social life and a challenge to public policies, urban development and built environment. To understand this evolution and lay down guidelines for construing the built environment several studies have been carried out at LNEC in the following areas:
- Equal opportunities and social cohesion: "Accessible housing" (Pedro 2002), aimed at setting up specifications to the design of housing for occupants with mobility strains;
- Adequacy to different lifestyles: "Emergent housing types" (Morgado 2005) aimed at supporting the development of housing models more suitable to new ways of life; "New technologies in housing" (Eloy 2005) aimed at supporting IT use in housing and residential areas; "Flexible housing" (Paiva 2002) and "Evolutive and adaptive housing" (Coelho 2003) aimed at studying strategies to improve the housing adaptability to different lifestyles;
- Participation and appropriation: "Humanized housing" (Coelho 2006) aimed at making a state of the art on the subject and setting research priorities for the future.

For the near future LNEC intends to develop studies on the following research subjects:
- Housing design strategies considering specific types of occupants, in particular aged people, youngsters and minority ethnic groups;
- Identification of barriers and opportunities, attitudes and behaviour changes, concerning sustainable construction.

8 CONCLUSIONS AND FUTURE RESEARCH ACTIVITIES

LNEC contribution and activity in built environment sustainability issues presented in this paper may be summarized as follows:

- Recent programmed research activity is characterized by an expressive, embracing and multidisciplinary approach covering many relevant areas. The objective interest of the results of this research is confirmed by their application in research studies by contract, and by LNEC researchers' participation in several related technical committees at national and European level.
- Several studies are either at the execution stage or planned for the near future, an evident sign of confidence on the continuation and increase of the LNEC commitment on sustainable construction issues. A broader and better integration and coordination of efforts is under way along with a wider and more structured policy towards the dissemination of the outcome of this activity. In this sense, the following actions are already planned: training courses, dissemination events and the organization of a national seminar centred on "standardization, regulations and sustainability".
- The focus on sustainable construction issues is a strategic option of LNEC. A special project called "Sustainable Buildings" has been recently initiated, intending to obtain external support, promote partnerships and attract young researchers interested in developing MSc and PhD theses in this field, besides other specific aims.
- The broad and multidisciplinary character of sustainable construction requires the coordinated efforts of the greatest number of the involved institutions. It is our understanding that this approach maximizes the potential of human and technical resources available in the national system of science and technology, leading to the progress of knowledge required by the construction sector.

The collection and presentation of the information contained in this paper was possible through the collaboration of the LNEC researchers who dedicate many of their activity to the progress of knowledge in this field. The authors express their gratitude for such valuable collaboration.

REFERENCES

Almeida, M. C., Vieira, P. & Ribeiro, R. 2006. Uso eficiente da água no sector urbano. Lisboa: IRAR, INAG, LNEC

Arsenio E. (2002). The valuation of environmental externalities: a stated preference case study on traffic noise in Lisbon. PhD thesis. Institute for Transport Studies, University of Leeds, UK.

Arsenio, E.; Bristow, A.L & Wardman, M. 2006. Stated choice valuation of traffic related noise. In *Transportation Research* Part D 11, p. 15 -31.

Coelho, A. B. 2003. Habitação evolutiva e adaptável. Lisboa: LNEC.

Coelho, A. B. 2006. Habitação humanizada. Lisboa: LNEC.

Coelho, A. B.; Cabrita, A. R. 1992. Espaços exteriores em novas áreas residenciais. Lisboa: LNEC.

Craveiro, J. 2006. O Homem e o habitat: território, poderes públicos e conflitos ambientais. Lisboa: LNEC.

Eloy, S. 2005. Novas tecnologias na habitação. Lisboa: Ed. LNEC.

Esteves, A. M.; Gonçalves, A.; Martins, I.; Coelho, S. & Carvalho, A. 2006. Leaching tests performed on low strength concrete, In *6th International Conference on the Environmental and Technical Implications of Construction with Alternative Materials; Proc. int. conf.*, Belgrade, June 2006.

Freitas, M. J. 2001. Habitação e cidadania. No trilho da complexidade de processos relacionais generativos. Lisboa: LNEC.

Gonçalves, A.; Martins, I.; Antunes, M. L.; Freire, A. C.; Baptista, F. & Fortunato, E. 2006. Guia para a utilização de materiais reciclados. Contribuição das novas Especificações LNEC. In *2º Congresso sobre Construção Sustentável promovido pela Ordem dos Engenheiros*, Porto, October 2006.

Lima, L. & Faísca, L. 1991. Impacte social do SISMEX 91. Lisboa: LNEC.

LNEC, 1979. Regras de qualidade relativas ao conforto térmico dos edifícios escolares – 1.º projecto. Lisboa: LNEC.

Machado, P. 2005. Quadros sociais do envelhecimento e da velhice em meio urbano: estudo sobre a mudança social na cidade de Lisboa. Lisboa: LNEC.
Martins, I.; Esteves, A. & Gonçalves, A. 2006. Avaliação ambiental de resíduos de construção e demolição. In *Encontro Nacional sobre Qualidade e Inovação na Construção – QIC 2006; Proc. nat. symp.*, Lisboa, 21-24 November 2006, Lisboa: LNEC.
Matias, L. 2001. Avaliação do desempenho térmico de protecções reflectantes aplicadas em coberturas inclinadas. Lisboa: LNEC.
Matias, L.; Santos, C. & Guedes, M. 2006. Condições de conforto térmico em edifícios em Portugal. Modelo adaptativo. In *Encontro Nacional sobre Qualidade e Inovação na Construção – QIC 2006; Proc. nat. symp.*, Lisboa, 21-24 November 2006, Lisboa: LNEC.
Menezes, M. 2003. Mouraria: entre o mito da Severa e o Martim Moniz. Estudo antropológico sobre o campo de significações imaginárias de um bairro típico de Lisboa. Lisboa: LNEC.
Moita, C.; Feio, S.; Nunes, L.; Curto, M. J. M. & Roseiro, J C. 2005. Bacillus subtilis/ CCMI 355 as a wood preservative against surface contaminant fungi. Optimisation of physical factors on the production of active metabolites. *International Biodeterioration and Biodegradation* 55 (4): 261-269.
Morgado, L. 2005. Tipos emergentes de habitação. Lisboa: Ed. LNEC.
Mourão, J.; Pedro, J. B. 2005. Sustentabilidade ambiental da habitação e áreas residenciais. Lisboa: LNEC.
Nunes, L.; Nobre, T; Gigante, B; Silva, A M. 2004. Toxicity of pine resin derivatives to subterranean termites (Isoptera: Rhinotermitidae). *Management of Environmental Quality: An International Journal* 15 (5): 521-528.
Paiva, A. 2002. Habitação flexível. análise de conceitos e soluções. Lisboa: FAUTL.
Paiva, J. V., Aguiar, J. & Pinho, A. (Coord.) 2006. Guia técnico de reabilitação habitacional. Lisboa: INH, LNEC.
Pedro, J. B. 1999. Programa habitacional. Vizinhança próxima. Lisboa: LNEC.
Pedro, J. B.; Paiva, J. V.; Raposo, S. & Vilhena, A. 2006. Proposta de um método de avaliação do estado de conservação de edifícios. Discussão e aplicação experimental. Lisboa: LNEC.
Pedro, J. B. 2002. Programa Habitacional. Espaços funcionais acessíveis. Lisboa: LNEC.
Pinto, A. T. 1997. Análise das características de comportamento térmico de edifícios com fachadas-cortina. Aplicação à região de Lisboa. Lisboa: LNEC.
Pinto, A. T. 2006. Qualidade do ar em edifícios de habitação. Recomendação para caudais de ventilação. In *Encontro Nacional sobre Qualidade e Inovação na Construção – QIC 2006; Proc. nat. symp.*, Lisboa, 21-24 November 2006, Lisboa: LNEC.
Santos, A. J. 2002. Desenvolvimento de uma metodologia de caracterização das condições de iluminação natural nos edifícios baseada na avaliação "in situ*"*. Lisboa: LNEC/FCUL.
Santos, A. J. 2006. Avaliação das consequências energéticas decorrentes do aproveitamento da iluminação natural nos edifícios em climas quentes. In *Encontro Nacional sobre Qualidade e Inovação na Construção – QIC 2006; Proc. nat. symp.*, Lisboa, 21-24 November 2006, Lisboa: LNEC.
Santos, C. 1994. Recycled corkboard, expanded polystyrene and autoclaved aerated concrete. Experimental research study as granular loose-fill insulations. In Charles Kibert (ed.), *Sustainable construction*; *Proc. intern. conf.*, Tampa, 6-9 November 1994. Gainesville: University of Florida.
Silva, D. S. 1996. *Social Sciences involvement in dams and safety management of downstream valleys: a first approach to Arade and Funcho's dam-break flood risk perception, in Almeida*, A. B., Viseu, T. (eds). Dams and Safety Management at Downstream Valleys, Balkema Editions.
Silva, D. 2006. À espera da cheia? Paradoxos da modificação do ambiente por via da tecnologia. Lisboa: LNEC.
Veiga, M. R.; Aguiar, J.; Silva, A. S. & Carvalho, F. 2004. Conservação e renovação de revestimentos de paredes de edifícios antigos. Lisboa: LNEC.
Velosa, A. & Veiga, M. R. 2007.Utilizção de um subproduto industrial como aditivo em argamassas de cal. In *VII Simpósio Brasileiro de Tecnologia de Argamassas; Proc. nat. symp.*, Recife, 1-4 May 2007.
Vieira, M. & Bettencourt, A. 2007. Rheology of pastes and mortars with fines resulting from ornamental rock waste. In *SCC2007 - 5th International RILEM Symposium on Self Compacting Concrete; Proc. intern. symp.*, Gent, 3-5 September 2007.

Thermal insulation of old and new buildings in Romania

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ABSTRACT: Once Romania has joined the European Community, environmental protection and energy saving have become top priority domains. European standards have become Romanian reference standards and norms. The present-day housing stock in Romania was mostly built between 1960 and 1989, without the adoption of any efficient solutions for thermal insulation. The operation of buildings more than 30 years old, has led to the occurrence of certain damages, because of the condense phenomenon into the walls. In Romania a governmental programme is carried out for the thermal rehabilitation of blocks of flats built before 1989. The investment for the thermal rehabilitation of buildings is financed equally by the government and the owners. This paper presents the situation of the housing stock in Romania, the requirements regarding the resistance to heat flow for the elements of the building envelope as well as the latest tendencies concerning the erection of durable constructions.

1 GENERAL PRESENTATION

An essential element of the sustained development of constructions is the promotion of efficiency and the rational use of energy. As the specific heat consumption and the consumptions involved in the hot water preparation in Romania are rather double compared to the ones found in the Western countries of the European Union, it seems of outmost necessity that special programmes designed for the increase of the energetic efficiency of buildings should be developed.

The experience of Western European countries, and especially Northern countries, that have carried out, after the energetic crisis they had to face in 1973, national programmes designed for thermal protection, stand out as real examples for the national politics regarding the implementation of thermal rehabilitation of the Romanian housing stock.

Based on the statistic data gathered through the census survey carried out for population and residences in Romania in 2002, the total number of housing stock is 4,846,572 buildings that practically comprise 8,110,407 residences. Out of the mentioned number, 1,138,945 buildings that comprise 4,257,964 residences are situated in the urban areas. 97% of the residences are private property. Most of the residences are situated in buildings aged between 15 and 55 years, with a reduced level of thermal insulation and a high degree of run-out. The structure of the Romanian housing stock depending on the age is illustrated in Figure 1.

The heating supply is being ensured for blocks of flats, at a rather high rate (90%), through a centralized system. In large Romanian cities, there have been created and extended, along the latest 40 years, centralized heating systems, that have as a source either thermal-electric power plants (urban central heating), or a local heating plant, responsible for the area, the neighborhood or a group of blocks. Most of the urban heating supply is connected to sources of heating production that belong to the national private power plant, the rest of the systems belonging to the local administrations and being managed by specialized enterprises controlled by the municipalities.

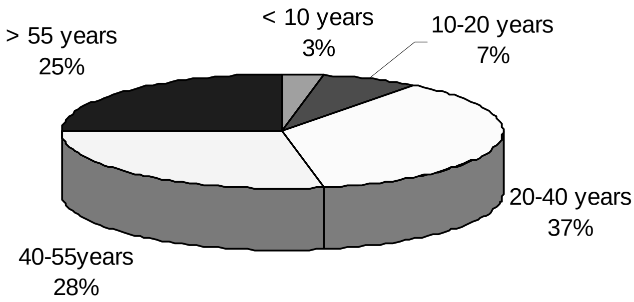
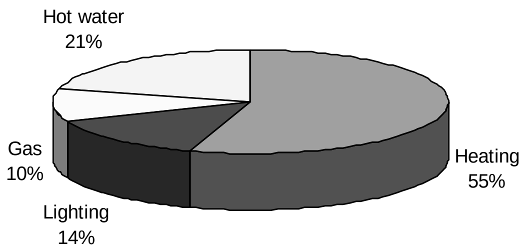


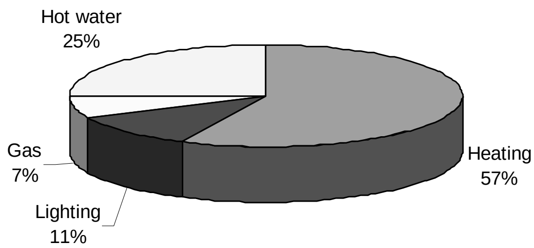
Figure 1. Status of the Romanian housing stock

2 STRUCTURE OF THE ENERGY CONSUMPTION WITHIN THE RESIDENTIAL SYSTEM

The weight of the energy consumption within the annual energetic balance of a medium-size apartment built between 1970-1985 is shown in Figure 2:



a. Romania



b. Western European countries

Figure 2. Structure of energy consumptions for an apartment

Considering the whole Romanian housing stock, the efficiency of the heat use for heating, hot water and cooking rises to only 43% from the total quantity of heat supplied by the sources. There can be noticed that the heating of the space is by far the largest final consumer of energy, both in Romanian and in Western European buildings.

3 TYPES OF ENVELOPE ELEMENTS USED FOR RESIDENTIAL BUILDINGS BETWEEN 1960-1989

The types of walls used for civil buildings until 1984 are different, therefore there are different thermal performances that depend on the composition of the walls. The main types of design used for the envelope walls of buildings built until 1984 are presented in Fig.3. A comparative study of the minimum resistances to heat flow required and the effective resistances to heat flow of the types of exterior walls used shows that the latter didn't meet the minimum requirements of thermal insulation. The walls show resistances to heat flow between the limits R_o=0,54...0,97 m^2K/W, that is 45...81% from $R_{o,nec}$. Table 1 shows the ratios between the effective resistances to heat flow and the resistances to heat flow required by the standards in force on the mentioned date, for each type of wall.

Tabel 1 The ratios between the effective resistances to heat flow and the resistances to heat flow required

Exterior wall type	A	B	C	D	E	F	G
Thermal resistance $R_{0,ef}$ [m^2K/W]	0.68	0.57	0.54	0.57	0.97	0.93	0.67
Ratio $R_{0,ef}$ / $R_{0,nec}$	0.57	0.48	0.45	0.48	0.81	0.77	0.56

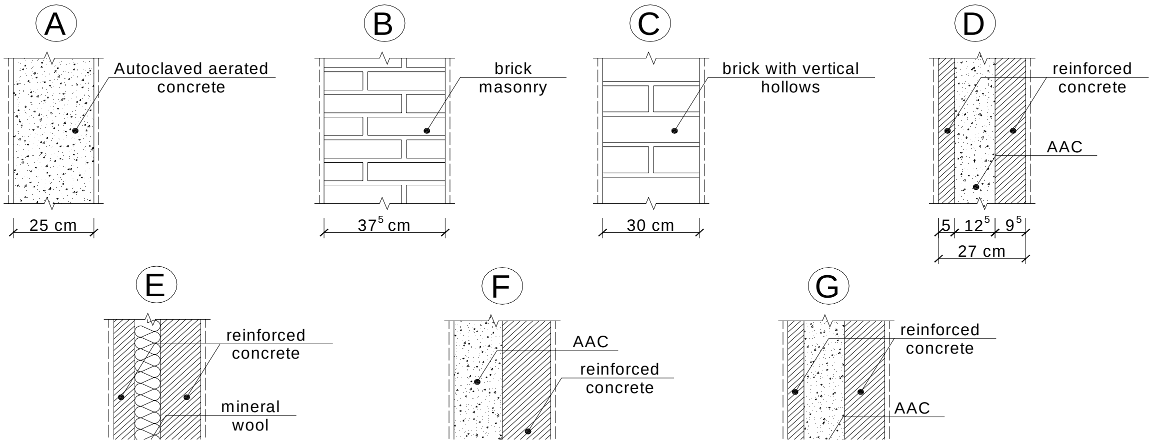


Figure 3. Design details for walls used until 1984

After 1984, the imposing of energy saving has led to a change of the design solutions for exterior walls used in residential buildings. The new solutions adopted have led to the exceeding of the minimum resistances required for envelope elements. Fig.4 gives the design details for exterior walls used for residence buildings starting with 1985.

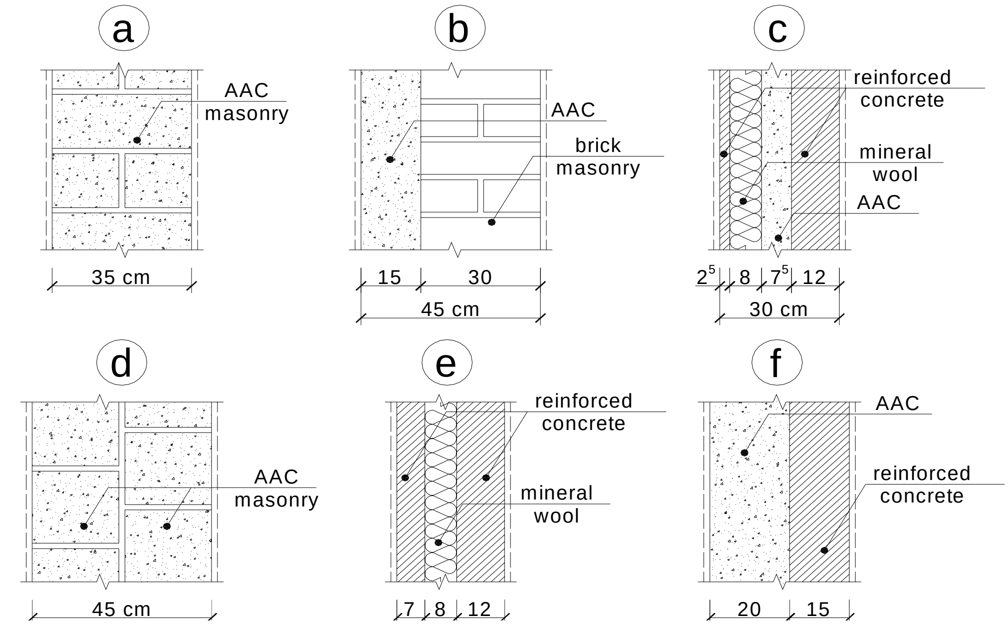


Figure 4. Design details for walls after 1984

Table 2 Comparative ratios between the effective and required resistances to heat flow

Exterior wall type	A	B	C	D	E	F
Thermal resistance $R_{0,ef}$ [m^2K/W]	1.84	1.38	1.63	2.43	1.56	1.61
Ratio $R_{0,ef}$ / $R_{0,nec}$	1.53	1.15	1.35	2.02	1.30	1.34

Table 2 shows the comparative ratios between the effective resistances to heat flow and the resistances to heat flow required according to the standards in force on the given date. There can be noticed that the principle solutions proposed for the improvement of the heat flow resistance exceeded the minimum resistance required, but in practice the solutions were not observed, this resulting in short-comings of the envelope elements, regarding energetic and comfort performances. The thermal insulation materials used were the cellular autoclaved concrete and the mineral wool, with various hygro-thermal characteristics. Polystyrene was considered as an expensive material at the time.

Therefore, we can conclude that, for most of the buildings, the elements of the envelope in contact with the exterior do not meet the thermal and hygro-thermal requirements, and a general rehabilitation is needed, with consequences on the hygro-thermal comfort and the energy saving.

4 THE EVOLUTION OF ROMANIAN STANDARDS REGARDING THERMAL INSULATION

Along the years, the Romanian standards that concern thermo-technics have introduced different values for the minimum resistances to heat flow, but also additional conditions regarding the diffusion of moisture within the constructional elements. The codes valid until 1989 comprised the following requirements regarding the envelope elements:

- the effective resistance to heat flow should be higher than the minimum resistance required determined upon the climate zone that the building is being erected and interior climate parameters;

$$R_0 > R_{0,nec} \tag{1}$$

R_o –Total resistance to heat flow [m^2K/W];
R_{oc} –Total resistance to heat flow taking into account the massiveness of the material [m^2K/W];
m – massiveness coefficient in function of the thermal inertia;
$R_{o\ nec}$ – Minimum required resistance to heat flow [m^2K/W].

- preventing the condense to occur on the interior surface of the envelope element, meaning to satisfy the following condition:

$$T_{si} > \tau_r \tag{2}$$

T_{si} –Temperature on interior surface [°C];
t_r – Temperature of dew point [°C].

- limiting the mass of condensed water inside the exterior envelope element, that corresponds to the satisfying of the following conditions:

$$m_w - m_v \leq 0 \tag{3}$$

$$\Delta W_{ef} \leq \Delta W_{allowed} \tag{4}$$

m_w – Mass of water condensed during the cold period of the year;
m_v – Mass of water evaporated during the hot period of the year.
ΔW_{ef} – Increase of water percentage condensed during the cold period of the year;
$\Delta W_{allowed}$ – Increase of water percentage allowed.

Tables 3 shows the time variation of the requirements regarding the resistance to heat flow of the envelope elements of Romanian buildings.

In the past 10 years, there have been developed in Romania a series of new standards, along with their specific guidelines for application. It is essential that there has been introduced a new concept regarding the thermal insulation of buildings, through the evaluation of the global insulating coefficient of the building, respectively through energetic certification.

Table 3 Time variation of the requirements regarding the resistance to heat flow

PERIOD	CODE	R_{min} [m^2K/W]			R' [m^2K/W]		
		Exterior walls	Flat roof	Floors over base-ment	Exterior walls	Flat roof	Floors over base-ment
1950 … 1961	-	-	-	-	-	-	-
1962 … 1968	STAS 6472 – 61	0.76	0.96	0.82	-	-	-
1969 … 1973	STAS 6472 – 68	0.80	1.02	0.87	0.60	-	-
1974 … 1975	STAS 6472/3 – 73	0.80	1.02	0.87	0.60	-	-
1976 … 1984	STAS 6472/3 – 75	0.80	1.02	0.87	0.60	-	-
1985 … 1987	STAS 6472/3 – 84	0.76	0.87	0.56	0.76	0.87	0.56
	NP 15 - 84	1.20	1.55	1.08	1.20	1.55	1.08
1988 … 1989	STAS 6472/3 – 84	0.76	0.87	0.56	0.76	0.87	0.56
	NP 15 – 87	1.20	1.55	1.08	1.20	1.55	1.08
1990 … 1997	STAS 6472/3 – 89	1.00	1.24	0.67	1.00	1.24	0.67
1998 … 2000	C107/3 – 1997	-	-	-	1.09	1.46	1.25
	C107/1 – 1997	-	-	-	1.40	3.00	1.65

The Romanian law states that, until the year 2010, all buildings should be energetically certified. Based on the energetic certification, advantages will be obtained concerning the systems of insurance, loans, taxes etc. The graph shown in Figure 5 presents the variation of the standards number and design guides that refer to the requirements of energetic performance.

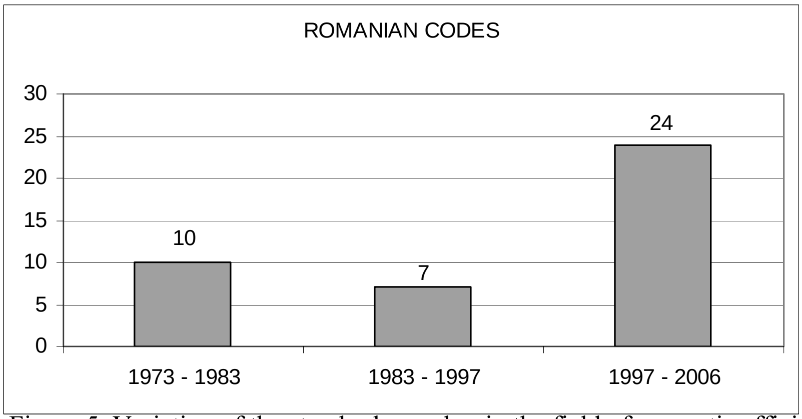


Figure 5. Variation of the standards number in the field of energetic efficiency in Romania

4.1 *Politics regarding the energetic efficiency. National programme for the rehabilitation of residence buildings*

From the analysis of the graph presented in Figure 5, there can be clearly noticed the last decade's trend to also introduce in Romania the concept of sustainable development directly referring to the energetic efficiency of new and existing buildings.

The Romanian Government has issued the Government Order no. 29/2000 regarding the thermal rehabilitation of the existing buildings and the stimulation of thermal energy saving; the provision sets up the legal framework for the thermal rehabilitation and modernization of all existing buildings and the installations thereof, aiming to the improvement of the conditions of hygiene and thermal comfort, to the decrease of the heat flow, the energetic consumptions, the cost of heating and hot water, and the polluting emissions generated by the production, the transportation and the consumption of energy. It is about the buildings situated in urban and rural areas (residences, public buildings, productions halls, etc.), where there are performed activities that require a certain degree of thermal comfort, according to the technical requirements in force. Based on the legislation in force, the local administrations financially support the investments that aim to the thermal rehabilitation of the housing stock, by supporting 50% of the investment, the other half being imposed on the owner.

The Government's programme for thermal rehabilitation of the existing housing stock also comprises some fiscal facilities for the owners. Thus, the ones who decide to rehabilitate their building shall beneficiate of an expertise, an energetic audit and projected design for thermal rehabilitation funded by the state budget, the relief from taxation when it comes to the issuing of the energetic certificate of the building and of the construction permit regarding the thermal rehabilitation works, respectively the relief from taxation regarding the residence all along the period of reimbursement of the credit obtained for the purpose of thermal rehabilitation.

5 EFFICIENT SOLUTIONS USED IN THE CONSTRUCTION OF THE „IULIUS MALL" COMMERCIAL CENTRE OF TIMISOARA

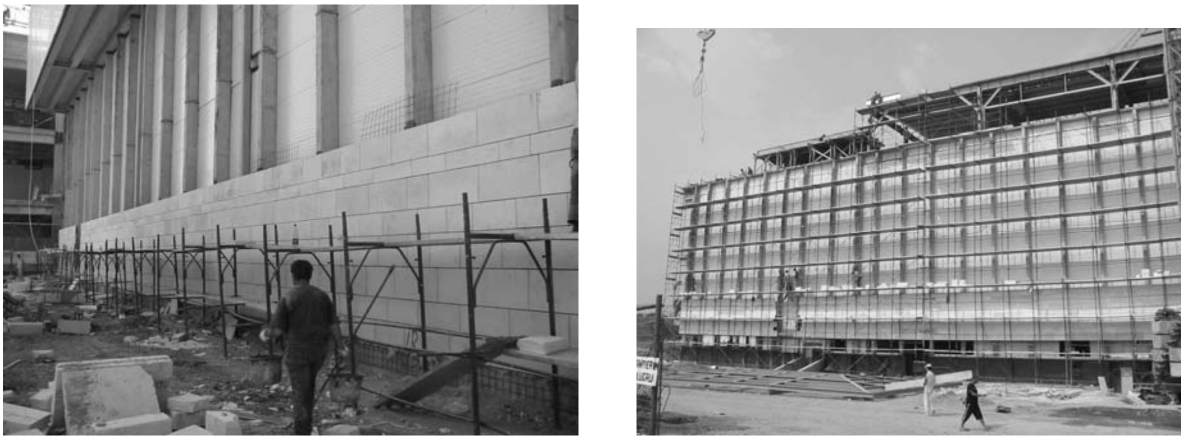
After 1989, one of the most important investment in the Western part of Romania is the "Iulius Mall" commercial centre. The completion of the building structure was a decisive stage of the investment. The quality control of the building erection is a component of the quality system.

The commercial centre is made up of several sections, each of them with an independent structure. The first development stage of the area and the building of the commercial centre consists in the construction of 15 blocks and one technical block. The building has a constructed area of 73, 000 square meters distributed on 3 levels and one terrace, hosting over 200 shops. Beside the shops, there is a movie theatre with several halls, a supermarket, restaurants, food courts, bars, kids land and sports centers.

A general view of the "Iulius Mall" Commercial Centre at the end of the construction works is presented in Figure 6.

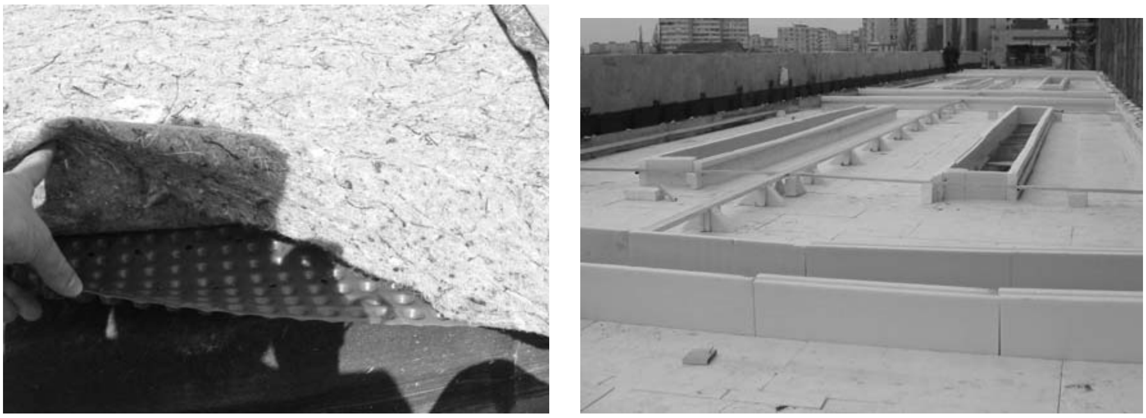
Figure 6. General view of the main entrance of "Iulius Mall" Centre of Timişoara

The photos included in Figure 7 show aspects from the execution of the exterior walls.



a. Detail from the installation of the envelope walls on the Southern facade   b. General view of the Southern facade
Figure 7. Aspects from the execution of the exterior walls

The application of the thermal protection and hydro-protection on the terrace is shown in Figure 8.



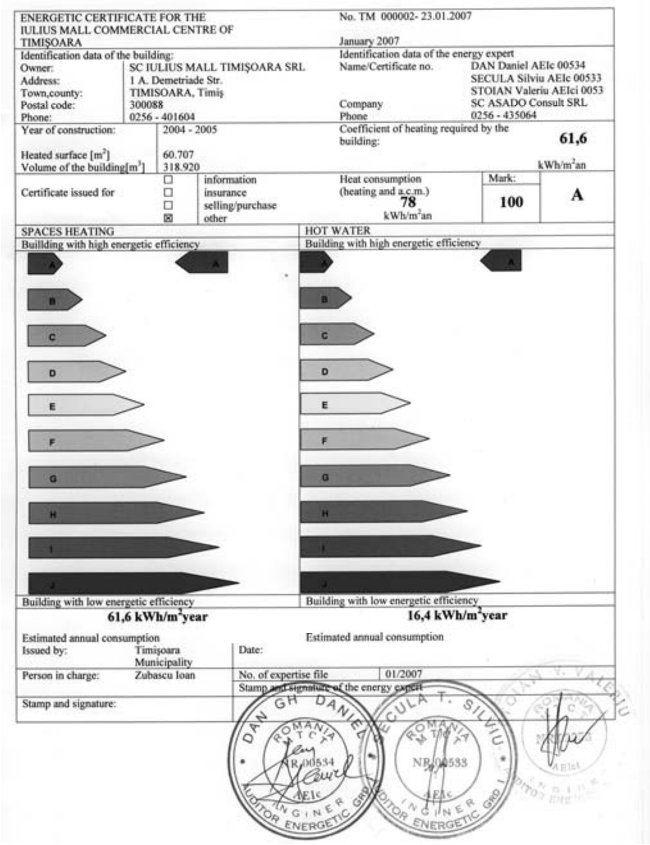
a. Terrace hydro protection   b. Terrace thermal protection
Figure 8. Details from the execution of the terrace hydro and thermal protection.

The most important material used for the constructional work of Iulius Mall Center is presented in the table 4.

Table 4 Materials used for the constructional work of Iulius Mall Center

No.	Material	Quantity
1.	Reinforcements and structural steel	> 3.000 t
2.	Concrete cast in site	> 80.000 m^3
3.	Mineral wool 5 cm thickness	13.847 m^2
4.	Sandwich panels 6 cm thickness	13.847 m^2
5.	Polystyrene 10 cm thickness	18.500 m^2
6.	Windows and doors	> 4.200 m^2

Based on the characteristics of the materials used and on the execution details of the „Iulius Mall" commercial centre, there was drafted the certificate of energetic performance of the building, presented in Figure 9.


ENERGETIC CERTIFICATE FOR THE IULIUS MALL COMMERCIAL CENTRE OF TIMIŞOARA
No. TM 000002- 23.01.2007
January 2007

Identification data of the building:		Identification data of the energy expert	
Owner:	SC IULIUS MALL TIMIŞOARA SRL	Name/Certificate no.	DAN Daniel AEIc 00534
Address:	1 A. Demetriade Str.		SECULA Silviu AEIc 00533
Town,county:	TIMISOARA, Timiş		STOIAN Valeriu AEIci 0053
Postal code:	300088	Company	SC ASADO Consult SRL
Phone:	0256 - 401604	Phone	0256 - 435064

Year of construction:	2004 - 2005	Coefficient of heating required by the building:	61,6 kWh/m²an
Heated surface [m²]	60.707		
Volume of the building[m³]	318.920		
Certificate issued for	☐ information ☐ insurance ☐ selling/purchase ☒ other	Heat consumption (heating and a.c.m.) 78 kWh/m²an	Mark: 100 A

SPACES HEATING	HOT WATER
Building with high energetic efficiency	Building with high energetic efficiency
A B C D E F G H I J	A B C D E F G H I J
Building with low energetic efficiency	Building with low energetic efficiency
61,6 kWh/m²year Estimated annual consumption	**16,4 kWh/m²year** Estimated annual consumption

Issued by:	Timişoara Municipality	Date:	
Person in charge:	Zubascu Ioan	No. of expertise file	01/2007
		Stamp and signature of the energy expert	
Stamp and signature:			

Figure 9. The certificate of energetic performance of the building

6 CONCLUSIONS

The reduction of heat loss through the construction elements is necessary in order to increase the energetic efficiency of a building. National and international programmes now in force aim to the thermal rehabilitation of residence buildings, as a priority measure within the sustained development of constructions.

The energetic performances of residential buildings are being evaluated in Romania by authorized energy experts who issue the certificates of energetic performances of a building. The energetic audit of a building requires, beside the energetic certification, the establishment of intervention measures and execution details designed for the improvement of thermal comfort.

The reduction of heat loss leads to the reduction of pollution and of the costs caused by the building maintenance.

REFERENCES

C107/1-3/1007 - Romanian standard for the calculus of the global thermal insulation coefficients for the civil residences

E. Mladin, M. Georgescu, D. Duțianu – Eficiența energiei în clădiri – Situația în Romania şi Acquisul comunitar, Bucharest Seminar, 2003

GT 036- 2002 - Guide for the thermal and energetic audit for the existing buildings and for the preparation for the hot water necessary for these buildings

GT 037- 2002 - Guide for the elaboration and assignment of the energetic certificate for the existing buildings

STAS 6472/2-83 - Building Physics. Hygrothermics. External climatic parameters

Construction sites environment management: establishing measures to mitigate the noise and waste impact

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ABSTRACT: In the last few years, the impact of construction industry on the environment has been increasingly recognized. Construction sites activities in urban areas may cause damage to the environment, interfering in the day to day of local residents, that frequently claim against dust, mud, noise, traffic delay, space reduction, materials or waste deposition in public space, etc. In a time that we see with pleasure improvements in construction process techniques, in materials innovation and in safety and healthy conditions, it is also necessary to take care of our environment. In this paper a review is made on the several inconveniences of construction impacts both on the sites and on the surroundings using literature and data from a survey carried out to National Association of Historical Centres. The impact analysis focus in detail the noise and waste impact. Forms to minimize these impacts are suggested.

1 INTRODUCTION

In the Historical City Centres (HCC) the negative effects of the construction projects have yet more relevance, given that they are urban areas with very particular characteristics. As they are touristic locations, it's necessary to maintain them as much as possible pleasant to live, work and enjoy. Furthermore, these areas frequently have significant restrictions regarding available space, bringing about more difficulties for the construction projects. Therefore the HCC, in view of their specificness, require from the intervenients of the construction sector a special attention in order to minimize the impacts of the construction projects.

2 CONSTRUCTION SITES INCONVENIENCES

The resulting inconveniences of the activities of a construction project are numerous. Regarding this theme, an attempt was made to order each impact by the importance given to each one in scientific publications, being the following the most frequently mentioned (Couto 2002)(Teixeira & Couto 2000):

- Production of residue
- Mud on streets
- Production of dust
- Soil and water contamination and damaging of the public drainage system
- Damaging of trees
- Visual impact
- Noise
- Increase in traffic volume and occupation of public roads
- Damaging of public space

3 SHORT DESCRIPTION OF THE INCONVENIENCES

3.1 *Waste production*

Like any other economic activity, construction uses natural resources and generates waste. The amount of waste generated by construction and demolition activity is substantial. Surveys conducted in several countries found that it is as high as 20% to 30% of the total waste entering landfills throughout the world. Moreover, the weight of generated demolition waste is more than twice the weight of the generated construction waste. Other studies compared new construction to refurbishment, and concluded that the later accounts with more than 80% of the total amount of waste produced by construction activity as a whole. The building activity at historical city centres tends to be an important waste generator because both refurbishment projects and new projects often include demolition (Teixeira & Couto 2000).

Figure 1. Construction waste left in Lisbon surroundings.

3.2 *Mud in streets*

Earth movements taking place in raining days often lead to the deposition of mud if tyres of lorries are not cleaned when leaving the construction area. Consequences are unpleasant aspect of streets, increased risk of car accidents and bigger maintenance costs for public space and private properties.

3.3 *Dust production*

Earth movements and demolitions often encompass the production of blowing clouds of dust with pernicious effects in the increasing number of those suffering from breathing diseases and unpleasant effects in deposition surfaces.

3.4 *Contamination of land and water and damaging of the public drainage system*

Construction makes use of a set of pollutant fluids that may spoil the land and adjacent pavements. Direct evacuation to the sewing system is inconvenient and should in some cases be forbidden because they may damage pipes and treatment plants. Paints, solvents, oils and washing water from construction sites are some examples of dangerous products. Pavements in historical city centres are sometimes of considerable value and the risk of degradation should therefore be avoided. Sewers are often very old and quite sensitive to possible aggressions. Repairing costs of such infrastructures tend to be high for several reasons and cause severe inconveniences both in living and visiting population.

3.5 *Damaging of trees*

The activity of construction sites may damage trees within the site and its vicinity. Trees being important natural elements in the urban landscape, as they beautify it, provide shades, shelter for birds, purify the air and retain moisture, among other things, their preservation is a must. In spite of their bulk, trees are delicate living beings; therefore, construction sites must be carefully prepared. Many times, the damage caused only becomes apparent a full year, or years after completion of the construction project.

Many actions may damage and even kill trees (City of Huntsville Urban Forestry Section 2000)(Gary 1999): soil compacting, increase in soil height, opening ditches and trenches, removal of topsoil, loss or damage to the roots, damage to trunks and leaves, and more.

3.6 *Visual impact*

Fences not preserved with bad graffiti or deteriorated placards contributes for environment degradation and may constitute a form of visual aggression.

3.7 *Noise*

Noise produced by a construction site may affect the right to silence, comfort and health of resident and visiting population and may influence normal activity of near by schools, hospitals and other economic activity. Main sources of noise in a construction site are pneumatic hammers, compressors, concrete mixers, operating machinery, several types of horns and acoustic signals, communication among workers, etc.

3.8 *Increasing car traffic and reduction of parking spaces*

Traffic of vehicles and machinery from the site or related to the site may introduce a significant increase in local traffic. Moreover, this type of traffic and typical narrow streets of historical city centres are often difficult to conciliate. Parking spaces usually available are often reduced due to the increase of demand of workers and suppliers.

3.9 *Public spaces damaging*

A análise dos impactos incluiu ainda a danificação do espaço público, uma vez que pode ser seriamente afectado caso não sejam tomadas precauções. Os danos mais frequentes são a danificação dos pavimentos, das zonas ajardinadas, dos lancis e grelhas dos sumidouros, e a acumulação de restos de argamassas e tintas nos pavimentos.

4 NOISE IMPACT

4.1 *National inquiry results*

The national inquiry carried out to the Portuguese association of cities with historic centers (Couto 2002), which 50% of the members answered had the following results regarding the most habitual prevention attitude for noise impact imposed by municipal authorities:

Table 1. Habitual prevention to the noise impact.

Habitual prevention attitude - noise	Answers (%)
Generally Compulsive Prevention – in the licensing of the construction project accordingly to municipal norms/regulations	6
Punctually Demandable Prevention – in the licensing of the construction project, in some circumstances	20
Eventually Demandable Prevention – during work execution due to the claims from affected citizens	47
Without Prevention – for considering the annoyance regarding the execution of the construction project	27

4.2 *Measures to mitigate the noise impact*

Generally speaking, all relevant emissions of noise should be object of reflection. At least, regulations should be accomplished, but in a historical city centre further criteria should be taken into account. Some examples are given below (Teixeira & Couto 2000)(Pinto 1997)(Worker's Compensation Board of BC 2000):

Construction plane:
- Obtain probable values for noise emission from the equipment to be used before commencement of works. This is a valuable aid to the choice of equipment
- Planning the choice of site or sites where the loudest equipment is to be placed; plant such as generators, compressors, etc., so as to cause the least possible inconvenience
- Preparing personnel so as to avoid inadequate use of plant and equipment, namely, running full power when the work does not necessitate it
- Careful planning of construction activities. It helps avoid loud verbal exchanges between the intervening parties
- Organizing the construction site so plant, equipment and vehicles can do a u-turn, rather than back out - which avoids the call sign for gears in reverse

Construction equipment:
- Internal combustion engines should preferably be substituted by electric devices
- High power equipment should be limited, so that main construction components may be manufactured outside and adjusted in place, thus requiring smaller electric tools
- Whenever possible emissions should be reduced through noise isolation materials
- Ready mix concrete should be preferred, otherwise concrete, mixers should be electrical
- Cranes should be substituted by electric lifts if possible
- Adjustment nuts should be preferred to wing nuts so that hammer shocks can be avoided when operating concrete shuttering
- Perform maintenance on machines so they do not output as much noise

Operation procedures:
- Walkie-talkies should be preferred to screaming at communicating with the crane operator
- Operation time for a noisy equipment should be minimised, especially if it can be replaced by an alternative less noisy construction process (e.g. the use of pneumatic hammer for cutting concrete can be reduced if shuttering is carefully levelled, boles are precisely located and irregular shapes are cut soon after dismoulding)
- Duplicate noisy equipment is there is space available (more noisy but less time of emission)
- Preview enough roam for machinery to turn back if rearward movement can be avoided (and also rear horn)
- Instruct workers to avoid the use of machinery in full power if it is not required

5 WASTE PRODUCTION IMPACT

5.1 *National inquiry results*

The national inquiry previously mentioned had the following results regarding the most habitual prevention attitude for the waste impact imposed by municipal rules:

Table 2. Habitual prevention to waste production impact.

Habitual prevention attitude - waste	Answers (%)
Generally Compulsive Prevention – in the licensing of the construction project accordingly to municipal norms/regulations	54
Punctually Demandable Prevention – in the licensing of the construction project, in some circumstances	29
Eventually Demandable Prevention – during work execution due to the claims from affected citizens	14
Without Prevention – for considering the annoyance regarding the execution of the construction project	3

5.2 *Measures to mitigate the waste production*

Construction waste is also an important topic to analyse despite the lower volume generated in comparison with demolition waste, because it is more difficult to recycle due to high levels of contamination, a large degree of heterogeneity and a considerable amount of chemicals. But it is produced in small quantities of a variety of construction materials during the project development and may be selected at the source prior to the recycling process. Additionally, an effort should be made in order to reduce their production on site and to increase their recycling value. The following actions may contribute for this purpose (Couto 2002) (Teixeira & Couto 2000) (EnviroSense 1996) (CIRIA 1997):

Construction planning:

- Co-ordination between designers and construction companies should be attended in the definition of materials and construction products
- Promote adequate communication among owners, project designers and contractors. Lack of communication is often the cause of partial demolition and removal of applied material, contributing towards needless output of debris
- Keeping the workers and concerned parties up to date, whether on the steps taken to minimize debris or the importance of such steps, as it is easier to take action when one knows the motives for it
- Before commencement of construction works, assess needed materials and make an effort to locate and acquire used materials beforehand, whenever possible
- Arrival of materials and products should be planned, according to available place on site and to production flow, to avoid excessive stocks and possible deterioration of goods and packs
- Stockpiles of sand, gravel, soil and other similar material should be located so that they do not spill and cannot be washed onto the adjacent street
- Accident spills of those materials should be removed prior to the completion of the day's work
- Quality control should reject defective materials at the time of delivery thus avoiding later disposal
- Materials should be delivered packed on site so that cracking can be reduced during transportation and on handling operations on site
- Packing conditions should be discussed with suppliers in order to reduce the number of packs and the amount of packaging materials, especially those not possible to reuse or difficult to have recycling waste
- Orders to suppliers of materials should respect sizing needs so that size adjustments can be avoided during construction
- Select products that output the least possible amount of residue or, at least, less toxic residue. A good example would be oil-based paint, which contain organic solvents that may render paint residue more dangerous. Water-based paint (latex) is safer to users and easier to handle. One should also try to use paints without metallic pigments, as these may also make the residue dangerous
- Store vegetable soil on piles no higher than 2 meters, and handle it as little as possible, as this may damage its structure
- Cut down as few trees and bushes as possible when cleaning out terrain to implant a construction site. Trees, trunks, branches and other vegetable matter, are solid residue that must be conveniently handled, at considerable cost
- Label packages of material as it comes in, and record the date for the reception of materials that deteriorate easily, so that the first to come in are employed first

Construction processes:

- Re-usable shuttering materials with eventual wreck value should be preferred even if investment costs are higher
- Cutting concrete due to lack of precision in design implementation shuttering and placement of holes should be avoided because it produces waste besides it is time consuming and involves noisy operations

– Protect materials from deterioration. Store them in sheltered areas if they are subject to degradation by rain or sunshine. Materials that can be degraded by mud or dust must be stored away from heavy traffic areas
– Waste selection (Couto 2002). Residue must be stored in segregated containers, according to the material origin; wood, metal, packages, aggregates, etc. Storing residue inconveniently has costs – the storage of dangerous residue is much more expensive than that of harmless materials – and may make the construction site unsafe. Piles of waste scattered throughout the site make accidents more likely; storing residue correctly not only bolsters reuse and recycling as it contributes towards health and hygiene at the site. Waste selection involves roam enough on site to dispose containers and allow for the operation of trucks and cranes and skill workers to the selection procedure, but these conditions are often difficult to achieve, especially in historical City Centres. Some private companies already operate in the area of waste selection and possible re-use of materials in the construction industry

Figure 2. Container by type of waste.

– Each container must clearly indicate what kind of waste it is meant for
– Value segregation of both large and small amounts of waste that have economic value, such as copper cables
– Storing in safe areas using adequately labeled containers for chemicals and oils
– Avoiding the mixing of unsafe waste, such as oil filters, batteries, paints and solvents, with harmless residue, as that would make the resulting mix a dangerous residue. Segregation of waste must maximize the potential for reuse and recycling
– To effect selective demolition

6 CONCLUSIONS

Lastly some legislation came into force either about noise and waste. However, presently, few measures have been carried out to improve the relationship among construction site activities the environment and citizens. Maybe due to the mobility of construction activity is difficult to make the construction companies – specially the smallest – to observe the law. There are some good examples but they are still insufficient. These suggestions pretend to make evident that some actions that are easily done can make the construction site environmentally efficient.

7 REFERENCES

Couto, Armanda 2002. *Environmental impact of construction sites in historic cities centres*, Unpublished MSc dissertation, University of Minho.

City of Huntsville Urban Forestry Section. 2000. *Managing Trees on Construction Sites*. [http://www.ci.huntsville.al.us/Landscape/Trees/UFSubpageConstruction.htm].

Construction Industry Research and Information Association (CIRIA) 1997. *Waste minimisation in construction – SITE GUIDE*. Special Publication 133.

EnviroSense, Delawere Department of Natural Resouces and Environmental Control. 1996. *A Pollution Prevention Guide for Building Construction and Demolition.* [http://es.epa.gov/program/regional/state/delaware/del-cnst.html].
Gary, Johnson R. 1999. *Protecting Trees from Construction Damage: A Homeowner's Guide*. University of Minnesota – Extension service. [http://www.extension.umn.edu/distribution/housingandclothing/DK6135.html].
Pinto, António C. 1997. *Estaleiros e o Ambiente. Internal Report*. MSc in Municipal Engineering, University of Minho.
Teixeira, José & Couto, Armanda 2002. Building Refurbishment in Historical City Centres. *In XXX IAHS World Congress on Housing. Housing Construction – An Interdisciplinary Task'*, 19-13 September, University of Coimbra, Coimbra, Vol. II, pp 223-229.
Teixeira, José & Couto, Armanda 2000. Construction Sites and Environment in Historic Portuguese Cities, *In CIB Symposium on Construction and Environment Theory into Practice*, 23-24 November, S. Paulo, Brazil.
Worker's Compensation Board of BC (Canada). 2000. Engineering Section Report. Construction Noise. [http://www.nonoise.org/resouce/construc/bc.htm].

How to attract consumers and real estate agents to sustainable housing

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ABSTRACT: The diffusion of environmental innovations in housing can only progress when the demand for sustainable housing increases. For this reason several initiatives have been taken in the Netherlands to get consumers and real estate agents (more) enthusiastic about sustainable housing. The results of four of these initiatives will be analyzed in this paper: the consumer magazine ‘Pure Living’, ‘open doors’ events, a course about sustainable housing for consumers and a course about sustainable housing for real estate agents. Despite the differences between these four initiatives three general conclusions can be drawn: the information should be carefully geared to the needs of the target group – the source of information should be unimpeachable – experience is more convincing than text or talks. The analysis also resulted in practical suggestions to improve the effectiveness of these or comparable future initiatives.

1 INTRODUCTION

Several initiatives have been taken in the Netherlands to get consumers and real estate agents (more) enthusiastic about sustainable housing. Four of these initiatives will be analyzed in this paper. The first initiative of which the results will be described is the ‘glossy’ about sustainable living: Pure Living (Puur Wonen). This magazine was on the market from 2003 till 2005. The second one is the open-door-event The Pure Living Relay. This event was related with the magazine and took place in 2004 in the province Noord-Brabant and in 2005 in the province Flevoland. Despite the discontinuation of the magazine the event will be organized again in 2007. This time in the province Drenthe. The name of this event will be different but the content will be comparable. The third initiative are workshops for consumers about sustainable housing. The workshops were held on location; a beautiful self-build-house which has been attractively described in a popular life-style-magazine. Several workshops were organized during the period from summer 2005 till autumn 2006. The fourth initiative was taken by the Dutch Association of Real Estate Agents and real estate experts NVM (Nederlandse Vereniging van Makelaars in onroerende goederen en vastgoeddeskundigen NVM). This organisation asked two specialists to organise a course about sustainable housing for real estate agents. This course is organized twice a year since 2005.

2 MAGAZINE PURE LIVING

2.1 description of the initiative

The magazine Pure Living was inspired by the American magazine Natural Home and some Dutch glossy living magazines. Focus group were the readers of the Dutch glossy living magazines. The idea was to tempt them into choosing sustainable building and living products by showing them the beauty and other qualities of these products. Showing the interiors of beautiful houses and describing the experiences of the inhabitants with sustainable products was the main goal of the magazine, together with providing practical information about shops, providers and information centers. The magazine started as a special of the professional building magazine Pure Building (Puur Bouwen). Because of the enthusiastic reactions on this originally once-only magazine more editions followed. The fact that the publisher was focused on the professional market resulted in the decision to stop the publication of the magazine after three years.

2.2 conclusions based on the experiences

The response on the magazine forms an indication for the conclusion that a glossy magazine with many interior reports, not especially focussed on sustainable topics but on overall quality, is a very effective way to attract people to sustainable housing. The magazine appeared to be attractive for people interested in housing in general. This means that in theory many people can be reached with a magazine like this. However, the fact that the publisher of Pure Living specialised in professional magazines and not in consumer magazines made it in practice impossible to reach all potential readers. In the busy magazine market and without a marketing budget, other magazines that can be linked or a clever free publicity campaign it is almost impossible to attract attention.
It would be much more effective and less expensive if regular, already popular magazines would pay attention to sustainable houses and products in a positive way. This conclusion is based on two other experiences. A report about sustainable housing in the Dutch popular mind style magazine Happinez resulted in a much bigger response than the response on all Pure Living magazines together. The other experience; an article about a Dutch supplier of mud-stucco in the most popular Dutch morning newspaper resulted in more orders for this product than all advertisements together in magazines focussed on sustainability.
Conclusion: People got tempted into choosing sustainable building and living products by showing them the beauty and other qualities of these products in attractive reports in magazines and newspapers. However; instead of starting a new magazine to produce reports like this it is more effective to focus on publishers and editors of already existing popular magazines and newspapers. By tempting them into the production of reports about attractive sustainable houses and the experiences of the people living within these houses, the market demand for sustainable housing- and building products will increase much faster en more cost effective than by starting a new magazine.

3 OPEN-DOOR-EVENT THE PURE LIVING RELAY

3.1 description of the initiative

The open-door-event The Pure Living Relay was an initiative of the magazine Pure Living. The idea behind the initiative is that during one day people living in sustainable houses in a specific region open their doors for everyone who is interested. Visiting people can also get more detailed information about the products they see and experience in the houses. In 2005 the Pure Living Relay was organized in the south of the Netherlands, in the province of Noord-Brabant. Thirty houses opened their doors. There was a very well organized information market with many suppliers presenting themselves. A small book with descriptions of all the houses was for sale. In 2006 the Pure Living Relay was organized in the newest province of the country: Flevoland. During this day 21 houses opened their doors. This time the information market was much smaller and instead of a book the houses were described in a free brochure. In 2007 more than 35 houses will open their doors in the province of Drenthe. In Drenthe there won’t be an information market. Information on paper will be available in the houses. All houses will be described in a free brochure. Afterwards a book will be published with reports about the most attractive sustainable houses in the province.

3.2 conclusions based on the experiences

The events in Noord-Brabant and Flevoland demonstrated the attractiveness of 'looking-inside'. Experiencing is much more convincing than reading or hearing about the subject. Especially houses with a special architecture attracted people. Visitors and owners of these houses were very enthusiastic about the event. Also owners of 'regular' houses, houses without visible features but with heat pumps or extra insulation, which were situated close to these special houses were enthusiastic. Owners from 'regular' houses not close to special houses were less enthusiastic. Only a few people visited these houses. Also owners of houses not in the neighbourhood of other participants were disappointed because of the small amount of visitors. It seemed that people try to visit a few houses in a short amount of time with a special house central in their route. The conclusion is that houses should be clustered.
A very positive side effect of the The Pure Living Relay is the amount of publicity about sustainable housing. Regional newspapers, magazines, tv- and radio stations but also national press used the event as immediate cause to inform their audience about sustainable housing.
A big disadvantage of the Pure Living Relay is the amount of time it takes to organize it. Especially the information market in Noord-Brabant was very time consuming considered the amount of people that visited the market. It seemed that people prefer to spend their limited amount of time in houses instead of on the market. Also the much smaller information market in Flevoland needed too much effort compared to the amount of visitors. As a result there will not be an information market during the event in Drenthe. Visitors can gather information on paper in the houses.
Even though many people received information about the Pure Living Relay less people than expected (between 300 and 400 persons) visited the event. It turned out to be difficult to motivate people to visit an event they haven't heard about before. For that reason the province of Drenthe chose for a combination with the yearly Day of Architecture which every year attracts many people. People are mostly interested in housing and interiors when they have plans to renovate, redecorate or buy a house. Another conclusion of the events is for that reason that using do-it-your-self and furniture shops and real estate agents to attract people can be very effective.

4 WORKSHOPS FOR CONSUMERS

4.1 description of the initiative

The Dutch popular mind style magazine Happinez published an article about the self build sustainable house of a family. The house and the nearby building offered a great opportunity to receive a small audience and the home owners were very experienced in talking to public. These circumstances resulted in the idea to offer the readers of the magazine a workshop about sustainable housing combined with a guided tour through the house. The response on this call was large. Several workshops with around 30 people each time were organised in this private house. The workshop started with a lecture of a specialist about the possibilities to build or renovate a house in a sustainable way. After a break the family told about their own experiences and guided the guests through the house. The workshop ended with personal advice for guests who wanted to make their own house more sustainable or people who wanted to build a sustainable house.

4.2 conclusions based on the experiences

The workshops were very successful and inspiring. Again mostly because of the possibility to experience sustainable elements. At the same time it created the opportunity to meet very interesting people with different backgrounds. The fact that all participants were readers of the same mind style magazine made it easy to communicate in an appealing manner for the whole audience. The target group was very clearly defined. The amount of time needed to organise these workshops was minimal. The disadvantage of this approach is the small output, only thirty persons each time were reached. More effective would be a combined event with a lecture for a much bigger group and an information market or other activities combined with a visit to one or more private houses. At the other hand; this is much more time consuming for the organisation.

5 COURSE FOR REAL ESTATE AGENTS

5.1 description of the initiative

The Dutch Association of Real Estate Agents and real estate experts NVM (Nederlandse Vereniging van Makelaars in onroerende goederen en vastgoeddeskundigen NVM) asked two specialists to organise a course about sustainable housing for real estate agents. Goal of the course was to inform the real estate agents about new regulations and developments, about the technical aspects of sustainable houses and about the possibilities to use the sustainable features as a basis for profit. Each real estate agent of the NVM is obliged to gather a certain amount of educational points each year. With this course the real estate agents could gain ‘points’. The course included a day with lectures and an afternoon in which the real estate agents could experience sustainable houses or sustainable housing products in practice.

5.2 conclusions based on the experiences

The course offers a rare possibility to inform the often extremely sceptical target group of real estate agents. For many of the students the educational points were the main reason to attend. Besides a few exceptions the overall level of knowledge about sustainability was low. The main fear of real estate agents seemed to be possible claims from clients about inaccurate information. It is safe for the real estate agent not to know anything about sustainable elements of the house. If they have the knowledge it has to be knowledge that goes into detail. This dilemma made the course very complicated. Sustainable housing is a discipline that can’t be communicated in every detail in one day. However; this is what the real estate agents expected. A possible solution for this dilemma is more detailed information on paper; fact sheets about technical solutions that the real estate agents can offer their clients. The source of this information should be named on the fact sheet. In that case real estate agents can reject claims about inaccurate information and the course can be used to inform them in a more global way about this discipline. To improve the motivation of the student the course should better be combined with a regional actuality in this field. In the province of Drenthe for example, the course will be combined with the open-door-event. Another improvement of the course has been limiting the oral presentation to day 1 and using day 2 for experiencing sustainable housing in a demonstration centre. Fortunately, several real estate agents were triggered by the several sustainable innovations that were exposed.

6 CONCLUSIONS

Based on the experiences with these four initiatives three overall conclusions can be drawn and several detailed conclusions.

The overall conclusions are:

- the information should be carefully geared to the needs of the target group
- the source of information should be unimpeachable
- experience is more convincing than text or talks.

The sub conclusions are:

- Focus on the existing press and try to tempt them into publishing about sustainable housing. This is much more effective (and cheaper) than starting a new magazine.
- Open-door-events are efficient because of the combination with publicity and experience. Small events like these are efficient too and less time consuming. It is very important that the ‘open houses’ are situated close to each other.

- Combine small open-door-events with general information, oral and on paper and provide the possibility for visitors to gather the personal information they are looking for (consults for example).
- Getting educational points is the biggest trigger for most real estate agents to follow a course about sustainable housing.
- Combine events like the-open-door-event with a course for real estate agents to involve this ‘hard-to-get’ group.
- Use do-it-your-self and furniture shops and real estate agent offices for spreading information because these are the places where the target group can be found.
- Make fact sheets about technical solutions that real estate agents can offer their clients. The source of this information should be stated on the fact sheet.

Promoting the environmental management systems into construction industry: the first step

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ABSTRACT: Construction projects and activities are associated with large environmental impacts in different areas. Principles of sustainable development should therefore be followed during construction just like in other industrial sectors. At the organization's level, one of the ways of achieving this goal is implementation of an environmental management system (EMS). The purpose of the paper is to present current environmental management trends in construction companies, which can be used as a baseline for establishing a policy to promote EMSs in construction sector. Benefits and obstacles associated with ISO 14001-compliant EMS implementation are discussed. Results of a survey related to environmental and quality management systems (QMS) in construction companies in Slovenia are presented. They show that the majority of responding construction companies has implemented QMS, and a large proportion of the respondents have also established an EMS. The major obstacles to the EMS implementation, as perceived by the respondents, are the associated high costs, and excessive documentation accompanying the EM. A successful policy promoting the EMS implementation in construction has to be targeted to the contracting companies as well as to the clients.

1 INTRODUCTION

Several environmental impacts are related to construction activities. The major impact stems from its consumption of materials, many of which are non-renewable. It is estimated that buildings account for about 40% of the materials entering the world's economy each year and for 25% of the world's usage of wood (Kein et al, 1999). In addition, site construction produces many atmospheric pollutants, and negligence on construction sites may result in the spillage of substances which are washed away into the water reservoirs. Large volumes of waste result from the production, transportation and use of construction materials and products. Significant amounts of energy are consumed during manufacture of construction products. Emissions to air are created during the transport of these products from the factory to the construction site.

Increasing environmental awareness exhibited over the past two decades in general has therefore reflected also in the field of construction; it has been recognized that construction activities have a large adverse impact upon the environment. This impact may be even more profound considering the fact that the construction site is a temporary production facility, predominantly exposed to outdoor conditions, with a large number of personnel belonging to different companies and organizations. Production processes take place in a less controlled and a more vulnerable environment when compared to the industrial production, therefore the risk of considerable environmental damage is increased.

It is clear that if the principles of sustainable development are to be implemented in construction on a company scale, general contracting companies need to use a systematic approach to environmental management. This can be carried out by establishing an organization's formal structure that implements environmental management - an environmental management system (EMS).

An EMS involves the formal system and database, which integrates procedures and processes for the training of personnel, monitoring, summarizing, and reporting of specialized environmental performance information to internal and external stakeholders of the company. The documentation of this environmental information is primarily focussed on design, pollution control and waste minimization, training, reporting to top management, and setting of goals (Melnyk et al, 2003). The system may follow specifications of an existing standard, e.g. ISO 14001 (2004).

1.1 *Standard ISO 14001 certification in Europe*

Adoption of the ISO 14001 is voluntary, and companies choose to become certified against the standard. Despite the voluntary nature of the certificate, an increasing number of companies worldwide initiating the implementation and certification process can be observed. The actual number of certified companies depends on several factors, such as the magnitude of environmental degradation, general environmental awareness, environmental regulations and governmental incentives in a particular country or industrial sector.

Change of the number of companies holding an ISO 14001 certificate with time in selected European countries is presented in Figure 1 for the time period from 1997 to 2005. It can be seen that the highest number of certificates was awarded to Swedish companies. Furthermore, the data for 2005 shows that the number of organizations holding the ISO 14001 certificate in Slovenia, 212 companies / 1000000 inhabitants, is comparable to the corresponding numbers in countries like Spain (200 companies / 1000000 inhabitants), Finland (175,8 companies / 1000000 inhabitants) or Czech republic. Figure 1 also shows that the number of awarded certificates increases significantly with time for all countries presented.

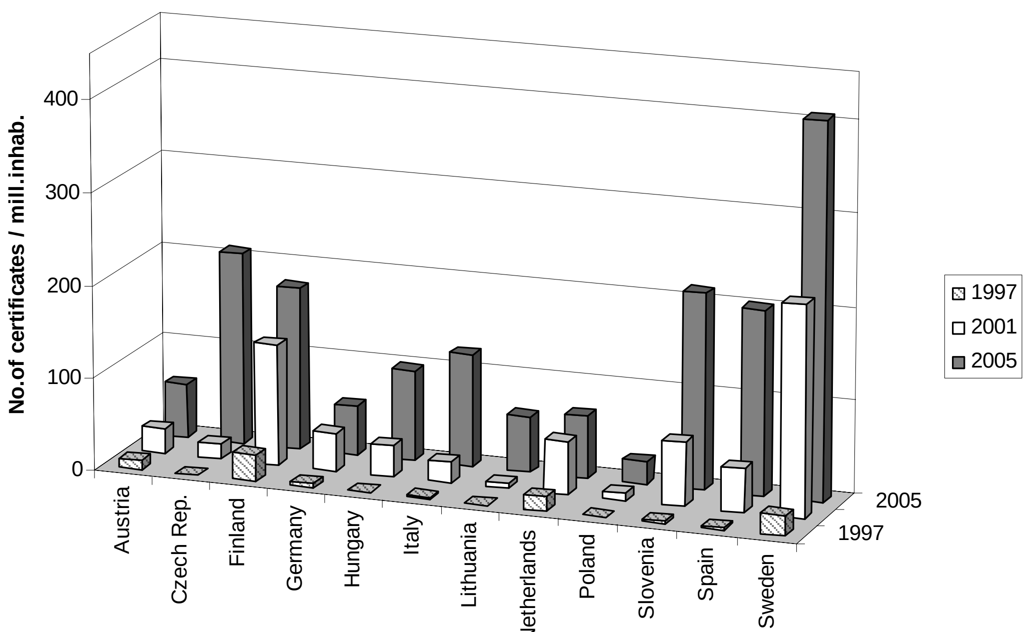

Figure 1. Number of companies holding the ISO 14001 certificate per million inhabitants for selected EU countries in years 1997, 2001 and 2005 (The ISO Survey, 2003; ISO survey, 2006)

1.2 *Problem statement and research objectives*

Throughout the world, construction sector is highly fragmented, diverse and consists of a large proportion of small and medium enterprises (SMEs). Various participants are encountered in a construction project: the client as the key stakeholder initiating the project, the designer, contracting and subcontracting companies, and various suppliers and consultants. The construction sector consists therefore of business entities of various sizes and trades.

In the EU countries, the contribution of the construction sector to the GDP ranges between 6 and 12%, therefore it can not be neglected in any national economy. Although the general trend shows that number of companies holding the ISO 14001 certificate is increasing, construction sector lags behind this trend in most countries. It is therefore clear that governments should have a clear policy as well as the strategy to promote the implementation of ISO 14001 compliant EMSs in individual construction companies.

Worldwide, projects promoting the EMS implementation in the industry are being initiated by governmental agencies and NGO's. To ensure the success of such projects, the initial environmental awareness level, the main drivers and barriers related to the EMS implementation have to be identified prior to project start. Furthermore, the outreach should be tailored to the business sector and cannot be generalized.

A successful policy targeted specifically at construction sector can therefore be established only if the current situation and general trends regarding the existing number of the ISO 14001 certificates and perceived drivers and barriers for the EMS implementation are identified.

The purpose of this paper is therefore to make the first step in establishing the Slovenian policy to promote ISO 14001 complying EMSs in construction sector. This means that as a starting point, an overview of the environmental management trends in Slovenian construction industry has to be established. This overview will serve as a baseline for subsequent policy recommendations. Slovenian construction industry can be considered representative of the construction industry of the new EU states which means that the established policy could be used in these countries as well.

1.3 *Methodology*

The overview of the Slovenian construction sector has been be carried out by a questionnaire-based survey. In order to obtain the data, a questionnaire consisting of 24 questions was sent to 56 Slovenian construction and engineering companies. The addresses were selected from the membership list of the Slovenian Chamber of Commerce – Construction Department. A total of 28 questionnaires were returned. One questionnaire was returned empty, with the explanation the company was going through bankruptcy, and one was filled out only partially. Three companies chose not to answer one question, notwithstanding, their questionnaires were assumed to be complete. In summary, 26 questionnaires were duly completed and returned, which gives a return rate of 47 %.

The questionnaire was divided into three main sections:

- general data
- quality management and
- environmental management issues.

The research that has already been carried out in this field worldwide served as a starting point for the formulation of the questionnaire and is therefore briefly summarized in the next section.

2 LITERATURE SURVEY

There are two areas of uncertainty that seem to be the major obstacles to the widespread adoption of EMSs by manufacturing companies. The first stems from the ambiguity of the relationship between pollution reduction and profitability. The second arises from the lack of reliable information about the differences in tangible benefits derived from certified EMSs versus those from an informal or less rigorous set of environmentally focused activities (Melnyk et al, 2003). For a long time, the erroneous view has prevailed that pursuing environmental goals was opposed to a sound business strategy. This view, however, eventually started to change and studies have shown that the improved performance measured by reduction of costs, improved quality, reduction of waste and increased lead times has been registered after the company has introduced a formal EMS (Melnyk et al, 2003).

Several researchers (e.g. Pun, 2001; Zeng *et al*, 2003) have focused their work to construction, pointing out the specific features of the sector. Case studies and surveys have been perfomed, and the following barriers to EMS implementation were identified (Christini *et al*,2004; (Tse 2001; (Ofori *et al*, 2000):

Client's role: the role of the client in the construction project needs to be recognized as a crucial factor that influences also the site and organization management systems.

Subcontracting system: typically, several subcontracting companies participate in a construction project. This creates an additional difficulty in the QMS and EMS implementation of the main contractor, as several organizations (which are often small companies) work simultaneously on one site.

Separate design and build: compared to industrial production, traditional separation of the design and build process is a unique feature of a construction project which creates a special challenge for the contractor. This feature is eliminated only when "design-build" method is chosen as the project delivery method (Ling et al, 2004). When traditional delivery methods are used, the contractor has no influence upon the design, including the choice of materials and components, which may restrict the potential of his EMS.

Lack of environmentally sound materials and technologies: often, the contractor is not able to properly identify and reduce his environmental impacts, as the available data regarding materials and technologies is insufficient to establish level of environmental soundness.

Lack of worker support: the educational level of a large number of workers taking part in a construction project is typically low, therefore they may not recognize the importance of the environmental problems, nor be willing to participate in the actions required by the environmental management, as it takes their additional efforts.

Magnitude of costs related to EMS implementation: implementation of an EMS, similarly to the implementation of a QMS, costs money. This expense may be viewed as unnecessary if general environmental culture in a certain sector / country is low, and there is no incentive from the government. This leads us to explicitly express as possible obstacles also

weak environmental culture among competitors and

lack of governmental pressure.

EMS standards unsuitable for construction: this is again an obstacle specific for construction industry. Contractors may perceive general EMS standards as unpractical for use in construction due to its special features.

Extensive documentation: a construction project is a fairly complex as well as dynamic process, therefore any additional documentation required neither by the regulations nor by the contract may be viewed as unnecessary, and perceived as an obstacle to the implementation of the EMS.

No competitor starts first: construction industry is highly competitive, and any additional cost generated within the company without visible financial gain, such as the cost of establishing the EMS, may be viewed as a factor of reducing the profit margin or the chance of winning the project.

Table 1. Number of employees of the participating companies.

Number of employees	%
0-50	12
50-200	49
200-500	31
500-1000	0
> 1000	8
TOTAL	100

3 RESULTS AND DISCUSSION

3.1 *Company profile and size*

76% of the responding companies are predominantly general contractors; 12% state that their predominant activity is construction products manufacturing, and 6% are engineering companies. A quarter of respondents states that their only business activity is construction.

The number of employees in participating companies is presented in Table 1. The largest proportion of the participating companies employ between 50 and 200 persons, and 12% have less than 50 employees.

3.2 *Quality management*

Quality management and QMS are important for the environmental management from the point of view that it is much easier to implement an EMS if there is already an existing QMS, especially if they are both standardized according to the ISO 9000 and 14000 series, respectively (Griffith, 2000).

The obtained answers show that 88% of the respondents have an ISO 9001 certified QMS. Only one responding company has a non-standardized QMS, and 8% of the respondents do not have a QMS. Most of the companies (65%) had their own QMS before implementing the ISO 9001 standard, and they could keep a major part of that system when the ISO 9001 was introduced into the organization. Out of the companies holding the ISO 9001 certificate, 65% claim that the number of won contracts increased after obtaining the certificate.

Motivation for the implementation of a QMS was also analysed. Responding companies were given the list of three possible driving forces:

- to meet the demands set by the client,
- to improve the transparency of the work processes, or
- to reduce costs.

They also had the opportunity to add their own driving forces for QMS implementation, and they were asked to rank the listed drivers from the most to the least important. The driving force listed as the most important scored 1.5 points, the second most and least important driving force scored 1.0 and 0.5 points, respectively. 9 out of the 23 respondents did not rank the drivers but only marked the selection of 3 optional answers. These answers were scored by 1 point. 6 respondents added other drivers, such as quality assurance, number of claims reduction, improvement of processes' quality, competitive advantage, re-organization of business processes and market appearance. The points of all answers were summed together. The results show that the most important driver for the implementation of the QMS is the improved transparency of work processes, followed closely by meeting the client demands. Cost reduction ranks third.

The last question of the section examines the attitude of the clients towards quality management. 36% respondents are usually, and 52% companies are sometimes faced by the requirement of holding an ISO 9001 certificate from the client. Only 12% of the respondents claim their clients do not require an established QMS.

3.3 *Environmental management*

The last section of the questionnaire consisted of questions related to the environmental management; 77% of the respondents (i.e. 20 companies) have an established environmental policy. This number is not much lower than the rate of companies having a quality policy (96%) and shows a fairly high environmental awareness in the Slovenian construction industry. Only respondents with an environmental policy were asked to answer the subsequent questions.

One of the goals of the survey was to determine the environmental issues the respondents are focusing on. The respondents were asked to rank the following issues:

- energy savings,
- recycling of materials,
- waste control,
- noise reduction,

- air/water pollution reduction.

These issues should be ranked according to one receiving most (rank 1) to least attention (rank 5). Rank 1 scored 1,5 points, and ranks 2, 3, 4, and 5 scored 1.25, 1.0, 0.75 and 0.5 points, respectively. Out of the 20 respondents, 14 respondents ranked the options listed above, and 6 respondents indicated the issues they were tackling but did not rank them. In this case, each answer received 1 point. The scores received for each optional answer from all respondents were summed together to obtain the total score, and the results are presented in Figure 2.

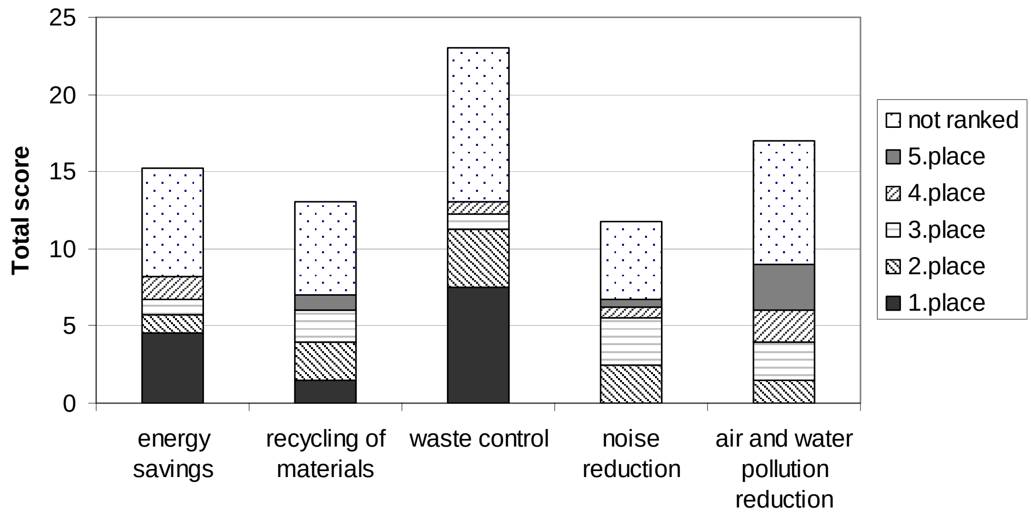

Figure 2. Contributions to total score of optional environmental issues to which the responding companies are focusing on.

The waste control is the environmental issue the responding companies are predominantly focussing on. This result can be explained by several reasons. First, since quantities of the construction and demolition waste produced are large, its control can contribute not only to better quality environment but also to reduction of costs. Secondly, a new regulation on construction and demolition waste management came recently into power, thus this issue attracted attention of the construction industry in general. Energy savings and air/water pollution reduction are the second most important environmental issues for the companies participating in the survey. Again, these are two issues that are to some extent related to cost savings and legal requirements, therefore the motivation for their tackling is larger. The respondents who chose to add other central environmental issues quote issues like improving public image, ecosystem preservation, separated collection of waste and cost reduction.

Table 2. Number of responding companies holding or planning to obtain the ISO 14001 certificate

Total no. of respondents	No. of respondents holding ISO 14001certificate	No. of respondents planning to implement ISO 14001
26	12 (46%)	9 (35%)

The next topic of the survey dealt with the presence of an EMS. 12 companies (i.e. 60% of the responding companies with an established environmental policy, or 46% of all respondents taking part in the survey) have an EMS certified against the ISO 14001 standard (Table 2). 2 companies have other types of EMS, and 6 responding companies do not have an EMS. This result is encouraging. It shows that the environmental awareness in Slovenian construction sector is increasing. It should also be noted that all companies holding the ISO 14001 certificate are also holding the ISO 9001 certificates. This empirically proves that it is easier to establish an EMS if the framework set by the standardized QMS is already established. The majority of respondents had elements of EMS before implementing the ISO 14001, and could use them in the certified system.

The next question wanted to find out how the respondents deal with their own environmental problems. The survey results show that 19 organizations, or 73% of all respondents, compiled a list of environmental potentially problematic issues. It is obvious that all responding organizations holding the ISO 14001 certificate have such list, as this is the standard requirement. Similarly, 18 responding companies (69%) are following the environmental legislation and are documenting the follow-up. This shows that even the organizations without ISO 14001 but having an environmental policy do use elements of an EMS in their practice.

The last question deals with possible barriers that can be encountered during the implementation of an EMS and are mostly specific for the construction industry.

A list of potential obstacles relevant for the construction industry was compiled based on the literature review as already discussed. The list is summarized in Table 3 in the order of importance as perceived by the companies participating in the survey. The respondents were asked to assess the obstacles and rank them on a Likert scale from 1 (least important) to 5 (most important). Similar list was also used in the study carried out in Hong Kong (Tse 2001).

An average grade was calculated from the grades given to each answer in Table 3 by the respondents. The resulting values show that Slovenian construction companies perceive the initial cost and the extensive documentation required as the two major obstacles to EMS implementation. It is interesting to note that in the view of the respondents, there is enough pressure from the government in the shape of new regulations. Further, the general form of the ISO 14001 standard is not perceived as a major obstacle.

Table 3. List of possible barriers in implementing ISO 14001–compliant EMS.

Barrier	Score
Expensive implementation cost	3,92
Complex documentation process	3,92
Weak environmental culture among other competitors	3,64
Sub-contracting system created difficulty to manage the EMS	3,48
Lack of client requirement supports	3,22
Separate design and build	3,17
Lack of environmentally sound technology/building materials	2,96
Lack of worker support	2,92
Unsuitable standards (different to interpret in construction industry)	2,92
Lack of governmental pressure	2,58
No competitor takes action first	2,04

4 CONCLUSIONS AND POLICY RECOMMENDATIONS

The results of the survey that was carried out for Slovenian construction industry show that a 46% of responding companies already have the ISO 14001 compliant environmental system. One could argue that companies holding the ISO 9001/14001 certificates are more likely to take part in the survey, and that the sample of the responding companies is not representative. Even so, the percentage of returned questionnaires is high and gives us an insight into the quality and environmental management trends in Slovenia. Further, the analysis of the driving forces to establish a QMS/EMS shows that client and its requirements play a vital role in spreading these systems in construction industry that can not be overestimated, even when the fact that the client must adapt the environmental awareness as a project objective has been already discussed in the past.

Major obstacles perceived by the respondents in the implementation of an EMS are costs, and creation and maintenance of additional (and excessive) documentation. Objectively, although it is clear that investments on resources and time are inevitable to establish the EMS, it may not be true that these costs are excessive.

4.1 *Policy recommendations*

An effective policy supporting the EMS implementation into construction industry has to be targeted towards both key players in the construction project: the client and the contractor.

As already discussed, the role of the client is crucial to the behaviour of general contracting companies. Taking into the account that a large proportion (the estimate for Slovenia is two thirds) of construction work are being financed through public funds, the Public Procurement Act should provide advantages for companies holding certified QMS and EMS. The present Slovenian Public Procurement Act that reflects the European Public Procurement Directive indeed includes incentives for contractors holding the ISO 9001 certificate, as it allows the client to add criteria other than lowest price to the tender, and explicitly outlines an ISO 9001 certificate as one of these additional criteria. Bidders holding the ISO 9001 certificate have in these cases considerable advantage. No similar option, however, is offered for holders of the ISO 14001 certificates. On European level, it is true that green public procurement recommendations already exist, but the clients are not obliged to use them. Educating the client representatives regarding green procurement must therefore be a clear element of a national policy supporting the EMS implementation into construction industry, and both public and private clients have to be addressed.

The general contracting companies should, on the other hand, receive relevant training to the key personnel and consulting specific for the construction sector. This would overcome the two obstacles perceived by the survey respondents, and decrease the cost of the system implementation as well as facilitate the creation of the accompanying documentation. Further, as the survey results show that all respondents holding the ISO 14001 certificate have also the ISO 9001 compliant QMS, it is worthwhile to promote quality management systems together with environmental management systems.

REFERENCES

Agenda 21 on sustainable construction 1999. CIB Report Publication No.237, Conseil International de Bâtiments, Rotterdam, The Netherlands.

Christini, G., Fetsko, M., and Hendrickson, C. 2004. Environmental Management Systems and ISO 14001 Certification for Construction Firms. *ASCE Journal of Construction Engineering and Management*, 130(3): 330-336.

Griffith A. 2000. Integrated management systems: a single management system for project control?, *Eng, Constr. Archit. Management*, 7(3): 232-240.

ISO 14001 2004. Environmental Management Systems – Requirements with guidance for use, International Standards Organization, Geneva, Switzerland.

The ISO survey of ISO 9000 and 14001 Certificates; the 12 cycle 2003. International Standards Organization, Geneva, Switzerland.

ISO survey of certifications 2005 2006. International Standards Organization, Geneva, Switzerland.

Kein, A.T.T., Ofori, G., and Briffett, C. 1999. ISO 14000: Its relevance to the construction industry of Singapore and its potential as the next industry milestone. *Construction Management and Economics*, 17: 449-461.

Ling, F.Y.Y., Chan, S.L., Chong, E., and Ee, L.P. 2004. Predicting performance of design-build and design-bid-build projects. *ASCE Journal of Construction Engineering and Management*, 30(1): 75-83.

Melnyk, S.A., Sroufe, R., and Calantone, R. 2003. Assessing the impact of environmental management systems on corporate and environmental performance. *Journal of Operations Management*, 21: 329-351.

Ofori, G., Briffett, C., Gang, G., and Ranasinghe, M. 2000. Impact of ISO 14000 on construction companies in Singapore, *Construction Management and Economics.* 18: 935-947.

Pun K.F., Hui, I.K., Lee, W.K. 2001. An EMS approach to environmentally friendly construction operations. *The TQM magazine*, 13(2): 112-119.

Tse, R.Y.C. 2001. The implementation of EMS in construction firms: case study in Hong Kong. *Journal of Environmental Assessment and Policy Management*, 3(2): 177-194.

Zeng, S.X., Tam, C.M., Deng, Z.M., and Tam, V.W.Y. 2003. ISO 14000 and the construction industry: survey in China. *ASCE Journal of management in engineering*, 19(3): 107-115.

Reasons to consider the deconstruction process as an important practice to sustainable construction

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ABSTRACT: In Portugal, the sustainability of construction has been looked into over the past few years, especially where quality, safety and natural/energetic resource-saving technologies are concerned. Deconstructing a building is the careful dismantling of that building so as to make possible the recovery of construction materials and components, promoting reuse and recycling. The concept arose as a consequence of the rapid increase in the number of demolished buildings and the evolution of environmental concerns within society at large. Deconstruction paves the way for the revaluation and reuse of construction elements and materials. A critically discussion by deconstruction importance is done using previous studies and data collected from present experiences. This aim is to present the main advantages of deconstruction technique to refurbishment, as well as the guidelines to design process aiming to guarantee a successful management deconstruction process, thereby contributing towards the economic sustainability of said process. The research projects which authors are involved are also discussed.

1 INTRODUCTION

There are now over 5 million houses in Portugal. 3,5 million are inhabited, 1 million is comprised of second or holiday homes and half a million are empty. Yet the construction industry is reluctant to adapt. From 1999 through 2002, 106,000 houses were built per year, and municipal zoning plans anticipate, in the north region of the country alone, houses enough for 15 million residents when the population is only about 3 and a half millions. Considering population density, Portugal has the most houses per resident in Europe and still is the country where more homes are built. The 2001 census listed 5,019,425 buildings, of which 1,222,280 were built before 1960 and constitute about one fourth of the total (Entrepreneurs Council for Sustainable Development 2004).

There is, then, this enormous patrimony that is waiting to be rehabilitated, as many of these buildings are sorely in need of interventions. Paradoxically enough, very little rehabilitation takes place in our country - indeed it is under 10%, whereas in other European countries it climbs to about 50%. The lack of interest in rehabilitation underpins behaviours that do not allow for sustainability in the construction sector. Partly, the attitude is connected to the fact that building rehabilitation involves knowledge of building materials and techniques that have been superseded. More often than not, rehabilitation of a building will stop at the preservation or restoration of the facade, disregarding the reuse of the materials inside, even though in some cases it can be recovered and employed in the new intervention. No-holds barred demolition produces an enormous quantity of debris which will, in most cases, only add to the pile of material to be used for landfills. Due to community concerns over potential impacts to the environment in developed areas, it is becoming more and more difficult to have landfills at such sites. On the other hand, having landfills in areas further away from human activity raises transport and power costs. An alternative to packing off these materials and constructive materials to a landfill is to choose deconstruction over the more common habit of demolition.

Deconstruction is the process of taking a building or structure apart, selectively dismantling and removing materials before the structure is demolished, or avoiding demolition altogether, and disassembling the entire structure, in the reverse order in which it was constructed (Hagen 2007). It is a concept that emerged due to the rapid increase of demolitions and growing environmental concerns expressed throughout society. Yet deconstruction processes are still perceived as interesting way to cut down on the production of debris but one that fails to garner general understanding and acceptance. For this to come about, environmental rules and regulations must be promoted. Deconstruction need to be developed and promoted. We need to raise awareness about the importance of deconstruction with the parties involved in the construction industry, especially owners, project designers and contractors (Liu et al. 2003).

2 DECONSTRUCTION: A TOOL IN BUILDING REHABILITION

In Portugal, often enough, in order to rehabilitate a building, some of its elements are demolished. This because they are either quite derelict or because new functions demand that elements be replaced. However, little or no reuse of materials and constructive elements has been taking place. Instead, selective demolition is the preferred method. We must point out that rehabilitation and deconstruction are concepts that fit the overall framework of sustainability in construction, as they both focus on the valuation of existing resources.

To rehabilitate a building means, basically, that we restore qualities to it that will allow for safe, comfortable use in a durable building appropriate to the goals in mind. There can be two sides to rehabilitation, whether we are talking about general-purpose contemporary buildings or those that constitute cultural and historic patrimony. In the first case, we may adhere to a formulation of the concept by the Royal Institution of Chartered Surveyors. Rehabilitation is: the extensive repair, renovation and modification of a building to have it suit economic or functional criteria equivalent to those expected of a new building that serves the same purpose. It may involve putting in place installations and service systems, means of access, natural lighting, equipment and finishes, using but the bare bones of the old building (Entrepreneurial Council for Sustainable Development, 2004).

The rehabilitation of buildings clearly dovetails with the concept of sustainable development. By valuing the recovery of existing buildings, the need for new construction is diminished. As a consequence, urban sprawl has less impact on surrounding areas whose environmental, ecological and agricultural value is often considerable. Another aspect of the matter is, deconstruction paves the way for the revaluation and reuse of construction materials and elements which would otherwise be treated as worthless debris and removed to storage spaces which are often not legally authorized to hold such materials. Furthermore, by valuing construction materials and elements, procurement of raw material is diminished, as well as the need to process and transport raw materials. The need to manufacture new components and products is also lessened, which has economic and environmental advantages (Couto 2006).

3 DECONSTRUCTION BENEFITS

Ignore deconstruction means create a pile of debris that can’t be viably reuse. The following figure attempts to depict that deconstruction permits the resorting procedures that enable separation and recovery of debris and by-products.

Figure 1. Sorted broken concrete and steel stockpiled separately (Guidelines for selective demolition).

Deconstruction allows to (Hagen 2007):

- Reuse and recycles materials: materials salvaged in a deconstruction project can be reused, remanufactured or recycled (turning damaged wood into mulch or cement into aggregate for new foundations)
- Foster the growth of a new market — used materials: recovered materials can be sold to a salving company. The market value for salvaged materials from deconstruction is greater than from demolition due to the care that is taken in removing the materials in deconstruction process
- Environmental benefits: salvaging materials through deconstruction helps reduce the burden on landfills, which are already at capacity in many localities. By focusing on the reuse and recycling of existing materials, deconstruction preserves the invested energy embodied in materials, eliminating the need to expend additional energy to process new materials. By reducing the use of new materials, deconstruction also helps reduce the environmental effects, such as air, water and ground pollution resulting from the processes of extracting the raw materials used in those new construction materials. Deconstruction results in much less damage to the local site, including soil and vegetation and generates less dust and noise than demolition
- Create jobs: deconstruction is a labor-intensive process, involving a significant amount work, removing materials that can be salvaged, taking apart buildings, and preparing, sorting, and hauling the salvaged materials

4 GUIDELINES TO DESIGN FOR DECONSTRUCTION

The benefits of deconstruction can be greater if during building design some issues were taking into account (Crowther 2000):

The strategies for material recycling suggested are:

- To use recycled materials - the incremented usage of recycled materials will encourage both industry and governments to investigate new recycling technologies and the creation of a greater support network for future recycling and reuse
- Minimizing the number of differing types of material - this will simplify the material organization process and reduce transportation
- Avoiding toxic or potentially harmful materials - this will lessen the contamination potential inherent to materials segregated and will also reduce potential risks to human health during disassembly
- Scheduling separate assembly of materials with differing reuse potential - this will keep large quantities of a given material from being contaminated by small quantities of another that cannot be separated
- Avoiding secondary finishing and coating whenever possible - they may contaminate the underlying material and make recycling less workable. Whenever possible, using materials that incorporate their own surface coating or finish or using separate, mechanically connected finishing
- Providing permanent identification of types of material - many substances, such as plastics, are not easily identified and should have Id tags or marks signaling “non-removable” or “non-contaminant” so as to make them easier to organize in the future
- Minimizing the number of differing kinds of components - this will simplify the process and augment reprocessing potential, making it more attractive when handling large quantities is possible
- Using a minimal number of easily degrading parts - this will reduce the number of parts that need to be removed during the remanufacture process and thus make reprocessing more efficient
- Using mechanical, not chemical connections - this will allow for the easy separation of materials and components and reduce material contamination and damage to the components
- Implementing chemical connections weaker than the parts to be connected - when chemical connections are used, they ought to be weaker than the components connected, so they are

easily broken during disassembly. For instance, mortar should be significantly weaker than the bricks it connects

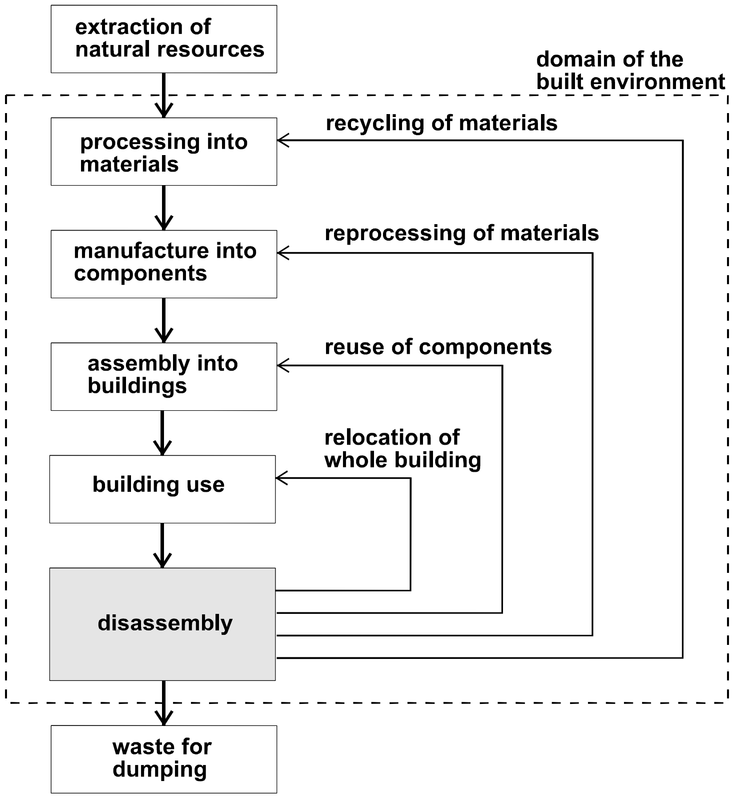

Figure 2. Scenarios for recovery of materials in a construction environment (Crowther 2000)

The strategies for component reprocessing suggested are:
– Minimize the number of different types of components - this will simplify the process of sorting on site and make the potential for reprocess more attractive due to the larger quantities of same or similar items
– Use a minimum number of wearing parts - this will reduce the number of parts that need to be removed in the remanufacturing process and thereby make reprocessing more efficient
– Use mechanical connections rather than chemical ones - this will allow the easy separation of components and materials without force, and reduce contamination to materials and damage to components
– Make chemical bonds weaker than the parts being connected - if chemical bonds are used they should be weaker than the components so that the bonds will break during disassembly rather than the components, for example mortar should be significantly weaker than the bricks

The strategies suggested for component reuse are:
– To choose an "open space" construction system that allows for changes in the compartmentalization of the building through replacement of components without significant construction work
– To use assembly technologies compatible with standard building practices - resorting to specific technologies will make disassembly harder and may call for special labour and equipment, turning this into a less attractive option
– To separate the structure of inner walls from casements or coatings - so as to allow for parallel disassembly, where some parts of the building may be removed without affecting others.
– To provide access to all parts of the building and to all components - ease of access will favour disassembly. Whenever possible, to allow that component recovery inside the building is made without specialized equipment

- To use components that make handling easier - allowing for handling at every stage; disassembly, transportation, reprocessing and reassembly
- To consider the space involved and the means necessary to dealing with the many components during disassembly - handling may call for connection points for lifting equipment or temporary support or buttressing mechanisms
- To ensure realistic slack among elements so as to allow for all the necessary movements during disassembly
- To use the smallest possible diversity of connectors - enforcing standards will make disassembly easier, faster, and demand fewer kinds of tools and equipment. Even if the end result is oversized connections, the time required for assembly-disassembly will surely be enough compensation
- To use a disassembly hierarchy connected with the components' lifespan - using components with shorter life spans where access and disassembly are easier
- To provide for permanent identification of component types - using international-standard barcodes may make it easier to divulge deposit banks and the commercialization of materials and components found in different places

5 CONTRIBUTION TOWARDS INCREASED COMPETITIVENESS OF COMPANIES

As is generally known, the competitiveness of the construction sector relies on the entrepreneurial capabilities of its companies, whose goal it is to provide quality, innovative service. This work aims to foreground knowledge in the fields of rehabilitation and reconstruction, giving companies an edge as far as deconstruction techniques are concerned. These techniques are preferable to undifferentiated demolition and meet legislative demands on reuse and recycling of materials; to which construction companies do not yet pay much heed. The pre-project on construction and demolition by-products and debris proposes implementation of debris and by-product management plans at the project design stage. This seems to be a correct, effective way to foreground the importance of debris management and to get all participants involved, beginning with the design stage and all the way down to implementation.

The plan specifications contemplate an estimate for the debris and by-products resulting from construction work. It then becomes necessary, at the design stage, to be more and more aware of the debris that will be produced. Adequate logging and shipping are also considered in this legislative document. These attitudes do indicate the path to follow.

It is very likely that, in the near future, much as is happening all over Europe now, new technologies for material reuse and recycling will be chosen over old habits. We hope this work will bring companies knowledge to help them adopt environmentally-sound attitudes; they will not only benefit economically but also in terms of their public image. Environmentally-sound positions are a great promotion tool, especially if you consider the many problems the world is going through right now that can be chalked up to our thinking in exclusively economic terms.

6 SCHEDULED INVESTIGATION PROJECTS

The authors are now participating in research projects on this problem. The main goals are to:
- Collect and analyze data on old buildings with strong masonry scattered across urban centers in Portugal, namely, their constructive characteristics and more frequently used construction materials
- Collect and analyze deconstruction techniques that help achieve sustainable rehabilitation of such buildings
- Propose methodologies for the implementation of deconstruction techniques that are adequate to the type of rehabilitation intended, that will allow for valuation of construction materials and elements (components) already in place, so that they are not randomly, indiscriminately or unnecessarily removed, so as to make them reusable
- Follow and conduct building rehabilitation experiments so as to analyze and validate the methodologies proposed for implementing deconstructive techniques
- Divulge and collect opinions from several participants in the constructive process

7 FINAL COMMENTS

At this writing, the construction industry is going through a process for the implementation of quality programs. These will surely contribute towards the reduction of debris and by-products created by the sector. However, the quantities produced are not going to plummet overnight. Furthermore, no matter how effective the changes made to constructive processes with a view to cut back on costs and debris generated, there will always be debris. Add that to demolition debris and by-products and you will still have a sizable amount of waste. On the other hand, work entailing total or partial demolition of buildings tends to occur more and more often in our country as a result of adaptation and improvement of said buildings. They must be refitted to meet new quality and comfort standards. New demands will be placed on older buildings, therefore.

So it is that research into practical solutions for the reuse of materials and components will combat the urban problem created by illegal landfills — bringing environmental improvement — and introduce new materials into the market that have great potential for use.

The production of legal documents that encourage more environmentally-sound behaviour, that is, that raises awareness and indeed makes the construction industry handle its debris and by-products more carefully, is vital to the sector, if it is to contribute at all to sustainable development, an obligation that is shared by everyone. Special mention must be made of the mandatory waste/debris/by-product management plan at the design stage. It seems to be a correct and effective way to highlight the importance of waste management and to get all the participants involved, from the design to the construction stage.

The change, however, must be accompanied by public awareness campaigns. It is not enough to stress that the plan is mandatory. The plan's importance must be addressed. It will be easier to reach our goals if we all know the advantages and importance of such a plan. Divulge and collect opinions from several participants in the constructive process.

8 REFERENCES

Couto, Armanda & Couto, Joao 2006. Desconstrução – Uma ferramenta para a sustentabilidade da construção, *In NUTAU`2006, Technological Innovation – Sustainability, VI Brazilian seminary of design management process in building projects*, School of Architecture and Urbanization, University of S. Paulo, S. Paulo, Brazil.

Crowther, Philip 2000. Building deconstruction in Australia. *In proceedings of CIB conference on Overview of deconstruction in selected countries*. Edited by Charles J. Kibert & Abdol R. Chini, University of Florida.

Entrepreneurs Council for Sustainable Development, 2004, *Rehabilition: the best away for sustainable construction*. [www.bcsdportugal.org].

Guidelines for selective demolition & On site sorting 2004, Public Fill Committee – Civil Engineering and Development Department. [www.cedd.gov.hk/eng/services/recycling/doc/sel_dem.pdf].

Hagen, Kevin 2007. *Deconstruction as an Alternative to Demolition – Helping the Environment, Creating Jobs, and Saving Resouces*. [www.associatedcontent.com].

Liu, Chunlu et. al. 2003. Technical Development for Deconstruction Management. *In proceedings of CIB conference on CIB Conference – Deconstruction and Material Reuse*. Gainsville, Florida, USA. Edited by Abdol Chini, University of Florida.

Methodology for the application of sustainable construction

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ABSTRACT: Many recognize the sustainable construction value as it contributes to the reduction of the environmental impact and to the quality, accessibility and productivity increase for whoever lives and works inside buildings. However, its economic advantages, which would be of great incentive for its expansion into the market, are still obscure. The objective of this paper is to present a methodology to assess the cost-effectiveness of the application of sustainable measures into buildings, through actions that establish a balance between environmental, economic and social factors. The methodology is based on the comparison of a case study (a building with application of sustainable concepts) with some reference buildings that will allow to show the triple bottom line added values. The aim is to achieve an optimum balance point, with an acceptable pay-back time, and to provide evidence of good economic results that encourage the investment into sustainable construction.

1 INTRODUCTION

This article was prepared with the objective of highlighting the subject of sustainable measures in building construction, a concept which has been commonly rejected for one main reason, its cost effectiveness. This problem is linked to some key issues:

- The lack of financial support, direct incentives and understanding of different advantages associated to sustainable buildings by governments, financial institutions and insurance companies.
- Builders and promoters in the real estate market have maintained a basic behaviour (and interest) to look for standard solutions that avoid an increase in the initial cost (investment) of new projects (construction phase). This way, they are transferring operational costs associated to the life cycle of the building to future owners.
- Finally, it is commonplace to observe the general conduct (building stakeholders) that is characterized by a restricted ability to consider the real costs generated during construction and operational phases in buildings. These costs are not considered or introduced in the market price formula, nor are they considered in the planning phase. Simply, they do not exist for building stakeholders. Some of these costs include: wastes, diseases and emissions (pollutants or CO_2).

For this reason some countries have been trying to develop different tools for economical and financial feasibility as well as, promote financial support, through incentives and subsidies that encourage the public and private investment into Sustainable construction. These are recognized by its demand-efficiency in energy (25 to 30%) and water, less volume of construction residues and the use of durable materials (Kats, Gregory, 2003).

In addition, it is possible to observe better indoor environmental quality, an increase in productivity among workers, a reduction in maintenance costs and other operational costs. On a global scale, the incentive results of sustainability in construction may provide an increase of 10 million new jobs (Sellier, Dominique, 2003), a decrease in taxes associated with a reduction in public health expenditure, and a reduction of CO_2 emissions (including consequences). As mentioned, direct benefits of sustainable buildings, are not only addressed to builders and end users, but also to other stakeholders involved in the construction, from the designers to insurance companies.

2 TOOLS TO ASSESS SUSTAINABLE CONSTRUCTION

Different countries have been developing studies and financial tools with the main purpose of implementing Sustainable construction and disseminating a new mentality into the marketplace. Many of these studies are based on tools to assess sustainability which are divulged in a country and tailored to its reality, such as LEED (Leadership in Energy and Environmental Design) in the USA, Breeam (Building Research Establishment's Environmental Assessment Method) in the UK, Casbee (Comprehensive Assessment System for Building Environmental Efficiency) in Japan, among others.

Defined by a methodology and an evaluation system, these tools aim to classify and recognize a sustainable building, and at the same time, they work as a guideline for builders and project designers. A well-known example is the research carried out in the United States, where 33 buildings were compared (certified buildings or in the certification process, by LEED) with other conventional buildings. In this analysis, certain assumptions were used such as discount rates -5%; period of analysis - 20 years; annual inflation - 2%.

It was observed in " The costs and financial benefits of Green Buildings" report (Kats, Gregory 2003), that an investment of 2% (on average) over the initial cost (compared to a conventional building), produces financial benefits 10 times higher than the referred investment (for a period of 20 years), considering the analysis of some cost categories, such as consumptions, maintenance, emissions and productivity.

The same report gives us a simple example of how to evidence these benefits. Applied to a real case and assuming that the construction costs in California are about \$150/ft2 to \$250/ft2, increasing 2% to these values, it would be equal to \$3/ft2 and \$5/ft2, respectively. The cost effectiveness analyzed in 20 years would be equal to \$48/ft2 and \$75/ft2. If these values did not include the inherent benefits concerning CO_2 emissions and productivity (just considering the reduction of energy and water demand, and less volume of waste) these would be around \$6/ft2 (Kats, Gregory, 2003).

Another interesting study (also in the United States), prepared by David Langdon (2004), had the objective of analysing costs linked to the construction phase of a "green building". This study showed that these costs (construction phase) drive the main decisions in sustainable projects (see figure 1). This report, which compared the construction cost per area in certified and non certified buildings by LEED, accounted for the cost of an information "database" of more than 600 projects (from 19 different States, typologies, locations, sizes and programs).

The referred study concluded that many projects reached the sustainability with their initial budgets or with a minimal additional increase (on average 2%).

In Europe, there are new incentives and legislation seeking to promote more aggressive policies in relation to the challenges of sustainable buildings. New studies have been carried out dedicated to cost effective buildings through sustainable construction concepts. These studies have been financed by the European Commission. Examples are the ASCOT model (Assessment of Sustainable Construction and Technologies Cost), a project carried out in 2004 by HQE2R and Cenergia. This tool helps users to implement a cost optimisation of construction in which sustainability measures have been applied.

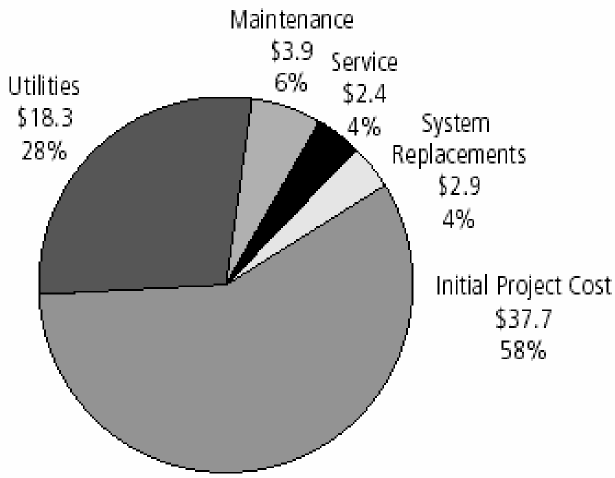

Figure 1. 30 years Life Cycle Cost - Building example
(Megan, Davis et. al, 2005)

There was also an increased interest in the subject of economic feasibility related to assessment tools and projects which can be applied to sustainable construction, such as SHE (Sustainable Housing in European): SHE has the main function of helping in the concept, cost analysis (initial cost and comparison to new buildings) and different options to obtain a higher viability of sustainable measures in projects. Another project, also co-financed by the European Commission, is the LCC-IP –"Guidebook-Integrated Planning for Building Refurbishment Taking Life-Cycle-Cost into Account". This project was constituted by several European case studies where an optimised relation between sustainable measures and cost – benefit analysis was demonstrated. Finally, it is important to make reference to the new government calendar in the UK, regarding the new "Zero Carbon Emissions" program in new houses.

These studies demonstrated that a substantial amount of additional investments made in sustainable projects, are based on specific costs such as simulations, introduction of new technologies and integration of sustainable practices into the project. The studies also evidenced that it is always important to introduce these measures as soon as possible, mainly in the design phase.

3 ECONOMIC FEASIBILITY ADAPTED TO THE PORTUGUESE REALITY

The above mentioned studies were carried out according to their national contexts. Thus, this paper intends to show a methodology that is being developed to assess the cost-effectiveness of some sustainable measures to be applied to commercial buildings, adapted to the Portuguese reality. The study will be carried out according to criteria of sustainability assessment tools based on "SbTool"- Sustainable Building Tool (still in the pilot phase to be adapted to the Portuguese case). The various stages of this methodology are outlined in figure 2 and described below.

3.1 *Guideline for sustainable construction and action analysis (1st step)*

The first step or the proposed methodology consisted on the development of a "Guideline for sustainable construction", a Manual with more than 400 actions adapted to Portugal, divided into five categories and identified in different project phases: pre-design, design, construction, operation and demolition. The categories are divided into:

- Planning;
- Energy Management;
- Water Management;
- Materials, resources and waste;
- Indoor Environmental Quality.

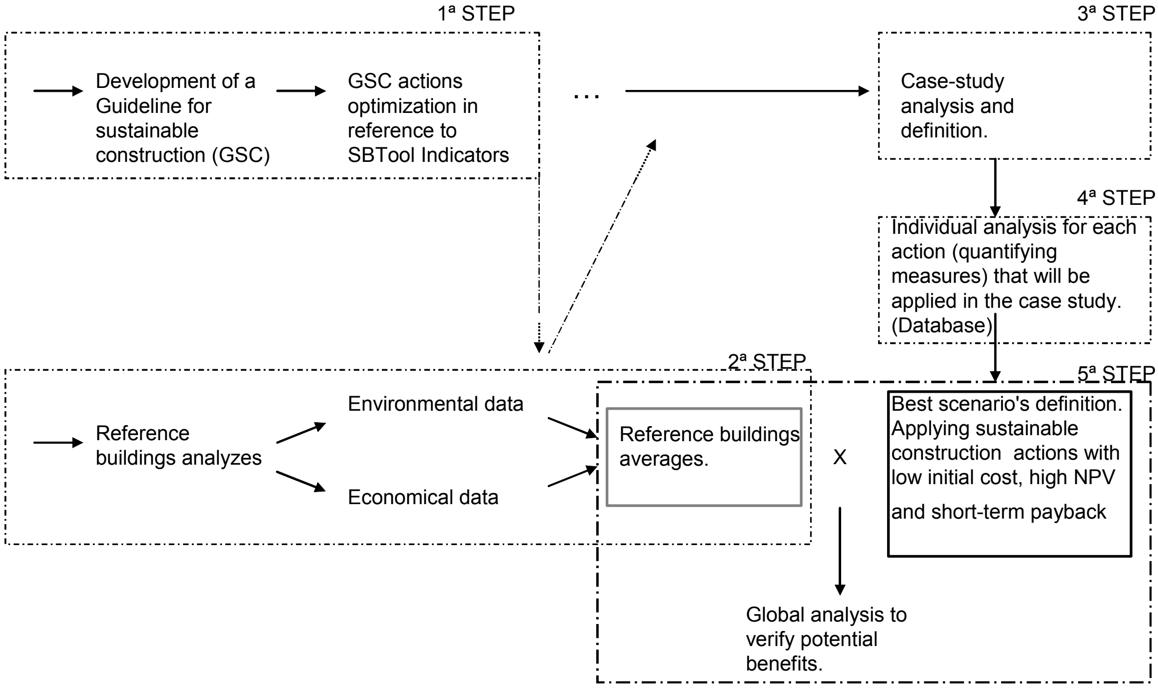

Figure 2. Structure of the proposed methodology.

As the implementation of 400 measures (from the referred Guideline) would be quite a complex procedure, an optimisation of the actions for analysis and validation was carried out based on the SBTool indicators, in reference to the following criteria (see figure 3):

· Specific analysis of just one of the project phases. In this case, the design phase will be examined as it is considered the most relevant to the validation (or application) of sustainable measures into Buildings.
· Only the indicators able to be quantified in the design phase are going to be considered as they allow for a larger impact during the building life cycle. The indicator categories to be analysed are Energy, Materials, waste and Water.

For an economical and environmental evaluation through this methodology, an individual application will be necessary. This will be demonstrated later in step 4.

3.2 *Reference building definition (2nd step)*

At the same time that actions were optimized through SBTool indicators, environmental and economic data have been collected on three existing Shopping Centres in Portugal (which used equivalent construction methods). These commercial buildings belong to the Chamartín Real Estate Company.

Through the obtained data of those buildings, which will be referred as “reference buildings”, it has been possible to establish efficiency indexes (consumption/m^2/year and consumption /1000visitors/year) as can be seen in tables 1 and 2. In addition to these indexes (energy, water, CO2 emissions, recycled and non-recycled waste), global values are going to be compared with national and international "benchmarks" (see table 3). Besides, these can be analyzed according to the IEE (index of energy efficiency), specified for shopping centers, which is comprised by the law 79/2006 (that emerged from the transposition of the EPBD - Energy Performance Building Directive into the Portuguese law) and that it can be visualized in the table 4.

It is important to point out that the shopping centres are situated in different locations, thus different climatic factors were obtained for the “reference buildings”. A basic comparison of the average values showed by the three buildings would be incoherent, as they would reflect the different climate features of the buildings performance.

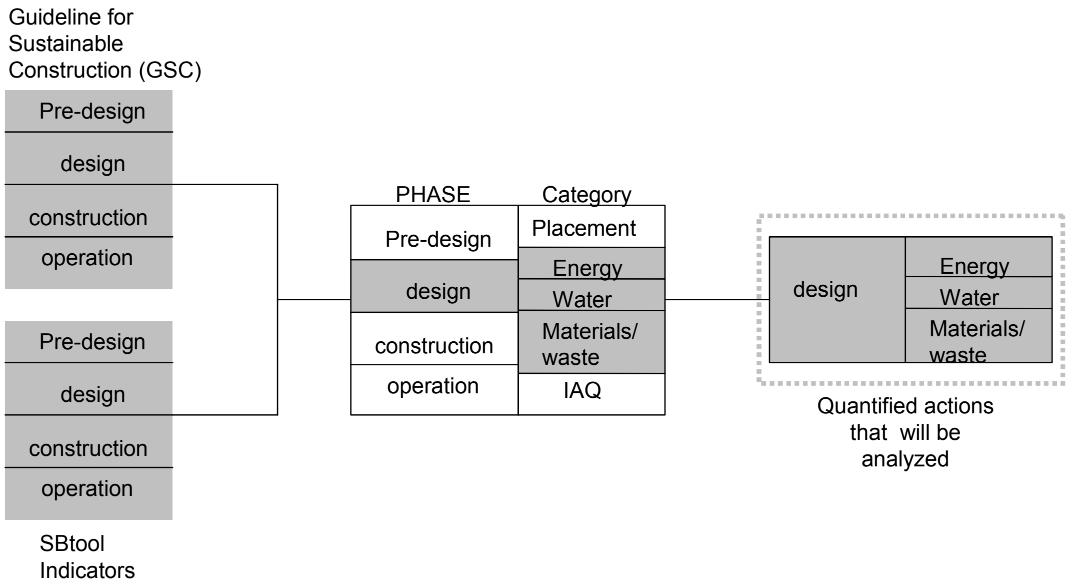

Figure 3. Selection procedures for the optimisation of the indicators to be analysed.

With this in mind and influenced by the methodology used in the Decree-Law 79/2006 to define the IEE index (Energy Efficiency Index) for different building typologies, as referred above, climatic correction factors are going to be applied to these shopping centres located in Coimbra (DVC), Porto (DVP) and Vila Real (DVD), when necessary.

Through these results, it will be possible to establish a comparison, on an economical and environmental level, between the "reference buildings" and a "case study".

Table 1. The efficiency index of the total demand (resources) and Chamartín's average per sqm (without climate correction).

DVS demand /sqm (construction area -GLA -Parking)							2006
	Economical data	*Environmental data*					
	Euros	Energy		Waste		CO_2emissions	Water
	Euros/m^2	kWh/m^2	tep/1000m^2	Recycled /m^2	Non recycled / m^2	$KgCO_2$/ m^2	m^3/m^2
DVP	32.96	474.86	137.71	6.91	20.87	196.59	0.83
DVD	22.12	283.50	85.07	6.24	11.08	117.37	0.50
DVC	29.43	370.69	107.50	6.79	21.45	153.46	0.79
Average	28.17	376.35	110.09	6.65	17.80	155.81	0.71

Table 2. The efficiency index of the total demand (resources) and Chamartín's average per 1000 visitors.

DVS demand /1000visitors			2006
	Environmental data		
	Energy	CO_2emissions	Water
	KWh/1000visitors	$KgCO_2$/1000visitors	m^3/1000 visitors
DVP	1458.80	603.94	2.56
DVD	1265.24	523.81	2.24
DVC	1105.02	457.48	2.39
Average	1276.35	528.41	2.40

Table 3. The average efficiency index of Shopping Centers - International benchmarks. (Source: CIBEUS and other researches).

Annual Average energy Intensity (existent Shopping Centres)			
	GJ / sqm	KWh / sqm	Kgep / sqm or Tep / 1000sqm
Canadian Shopping Centre average	1.30	361.40	**105**
UK Shopping Centre average	1.04	290.00	**84**
The efficiency index specified for the EPBD in Portugal	2.30	655.00	**190**
Portuguese reference building	1.35	376.35	**110**

Table 4. The efficiency index, specified for the Shopping Centre in agreement with the decree-law 79/2006 (EPBD, 2006)

Existent buildings		
Activity types	Building tipology	IEE (Kgep/ sqm.year)or (Tep/1000sqm.year)
Commercial	Commercial centre	**190**
New buildings		
Activity types	Building tipology	IEE (Kgep/ sqm.year) or (Tep/1000sqm.year)
Commercial	Commercial centre	**95**

3.3 *Case-study definition (3rd step)*

This methodology will be applied to the largest Iberian Shopping Centre, which also belongs to “Chamartín Imobiliária S.G.P.S., S.A”. The building is being constructed in Amadora, near Lisbon with a total construction area of 423.000 m^2, including parking and 122.000 m^2 of GLA (Gross Leasable Area). This project was designed with a new concept brand for Shopping Centres, named “Dolce Vita”, a world market reference. It will include wide reading spaces, stores, a food court, recreation areas and supermarkets.

The chosen typology is quite relevant (in relation to its dimension) since a commercial building of this size will have high environmental, social and economical impacts (Environmental impact, resulting from its construction and management, social and economical impacts, resulting from future changes in local reality, employment and road flow increases).

An evaluation of the shopping centre, which is presently in the construction phase, has been carried out in order to verify if any sustainable measures have already been applied. Environmental and economic performances related to the referred measures (already applied) are going to be identified and the probability of the building (through simulation) reaching SBTool indicators will be evaluated.

3.4 *Cost-effectiveness of sustainable construction Indicators and database creation (4th step)*

In this stage, the cost-benefit analysis of each sustainable measure (applied individually) will be analysed through a simulation carried out in the selected commercial building previously mentioned. The information will be organized in a database that is structured like shown in figure 4. Firstly, the information will be organized by categories that can be quantified (energy, water and material). Afterwards the information will be structured according to the identification in the SbTool. Regarding to the figure 4, it is possible to understand the referred adaptation, because the information utilized in the 2nd and 3rd rows result from the SBTool organization.

The expected results for each measure are the investment cost, generated NPV (Net Present Value) and the payback period. These measures will be divided into 2 groups with different reference values, such as score 3 “good practice” and score 5 “the best practice”, as defined by SBTool benchmarks (see figure 4). The fulfilment of the database will follow the following steps:

1. Identification of SBTool indicators that correspond to the project phase and that will be analysed in the database. For each indicator, there are actions to reach objectives.

2. Identification of actions, which were already identified in the studied building, and which consider the SBTool indicators in the database. Analysis of actions should be accomplished through the comparison with conventional actions used in the reference buildings.

3. Identification of actions that were not found in the studied building and that should be filled out in the database. Analysis of these actions should be accomplished through the comparison with present existing measures in the studied building, regarding potential changes.

3.5 *Best scenario formulation – Sustainable Building (according to the application of the studied action) - (5^th^ step)*

After completing the database, the ideal definition of best scenario will be accomplished. This scenario will be made up of actions that have a tendency which is oriented for such characteristics, such as: low initial cost, high NPV and short-term payback, which assure a "good practice" level, according with SBTool methodology.

The selected actions with the referred characteristics, require that other actions will be added (with different characteristics), thereby, assuring the SBTool validation in the execution phase of the different categories (energy, water and materials).

Apliccation example

Case-study: DVT Shopping Center **[A]**
Type ocupancy: RETAIL and Office
Phase: Design Phase
Region Location: Amadora_Lisboa

Related category	Issues	SBTool Intent	Actions already proposed	score 3			score 5				
				Investment cost						NPV (20 years)	PayBack
				L	M	H	L	M	H		
Energy	B3.1	Plans to use off-site energy that is generated from renewable sources	☑			x					???
Water	B5.3	Design measures and management plans to limit the use of potable water for building systems and occupant needs	☐								

[B] **[C]** **[D]** **[E]**

[A] -Building`s description

[B]- Indicators that will be quantified, according to the following categories: energy, water and materials.

[C]- Issues - Identify the benchmarks that are analyzed by SBTool (for instance: B.3.1 is an indicator of renewable energies, which are included in the “Energy and resource consumption issues).

SBTool Intent - Actions to accomplish the benchmarks objectives.

[D]- Identification of Sustainable Actions already existent (or not) in the case study.

[E]- Cost benefit analysies for each action, identifying:

Investment cost: L- Low cost
M- Medium cost
H- High cost

NPV (20 years) - Net Present Value - the net result of an investment, expressed in today`s euros; the present value of future cash flows minus the present value of the investment minus any associated future cash outflows.

Simple pay back time - the lenght of time needed to pay back the initial capital investment, usually expressed in years. This is the simplest form of the cost-benefit analysis.

Figure 4 – Database structure – where it will be identified the actions and the indicators under study.

Through the application of the studied measures, a comparison between the best scenario (for a specific typology – Shopping Centre) and the building in study will be obtained. It will include the evaluation and comparison with the present methods and measures carried out in the construction of the building, thereby evidencing a set of results that can be revised in the present project.

The explicitness and transparency that demonstrates efficiency benefits, and how to reach economic value in sustainable buildings, are a decisive incentive for stakeholders and for real estate market in general.

However, it is important to remember that this study will be defined for a specific typology in a certain area. Therefore the result will be conditional and will not allow a direct and immediate application of the best scenario methodology in other projects.

Nonetheless through its main output information (costs definition, database output and new methodology), this study can serve as an important guideline to help different stakeholders involved in new sustainable building projects focused on economical benefits.

4 CONCLUSIONS

This paper seeks to define methodologies and objective contents to achieve newer and larger real estate projects (services /commercial), supported by sustainability concepts.

The use of "SBTool" in this study intends to reach desirable results through the use of a rigorous and recognized tool among Universities and Academic environments. On the other hand, it has been positioned as an essential resource for study and development of the Sustainable Building Evaluation.

Finally, this study seeks to define new methodologies and analysis aiming to integrate different action fields such as sustainability, functionality and economic feasibility (cost effectiveness) which more than often are used separately.

5 REFERENCES

Building Research Establishment Lta. (BRE). 1988. BREEAM – BRE Environmental Assessment Method. BRE: UK.

Caccavelli, Dominique. 2005. *Integrated Planning for Building Refurbishment Taking Life-cycle cost into account*. Brussels: European Communities.

CIBEUS.2002. The commercial and Institutional Building Energy use survey. Canada.

Davis, Megan et. al. 2005. *Guideline for life-cycle cost analysis*. Stanford: Stanford University.

Drouet, Dominique et.al. 2004. *Economic instrument and sustainable building*. Paris: ARENE.

EPBD-Energy Performance Building Directive.2003. Directive 2002/91/CE of the European Parliament and Council from 16 of December 2002. Official Journal of the European Communities.

Green Building (GBC). 1996. *Green Building Tool (SBTool)*. Canada.

Kats, Gregory. 2003. *Green Building Cost and Financial Benefits*. USA.

Langdon, Davis. 2004. *Costing green: A comprehensive cost Database and Budgeting Methodology*. USA.

Morck, Ove. 2004. The ASCOT model: Assessment of sustainable construction and technologies cost. Paris: Cenergia.

RSECE – Decree-Law nº 79/2006. 2006. The regulation for buildings with installed HVAC systems. Portugal

US Green Building Council (USGBC). 1999. Leadership in Energy e Environmental Design (LEED). EUA

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The Calculation Model of the New Portuguese Thermal Regulation – put side by side with Dynamic Simulation

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ABSTRACT: Nowadays, there is a global urge to reduce the energy consumption, in order to slow down the environmental pollution. Since the building sector is one of the main energy consumers in Portugal, there is a great pressure for enhancing the energy efficiency in this sector. Currently the measure with more potential to effectively reduce the buildings energy consumption is the new Portuguese thermal regulation. However, to guarantee a good performance in reducing the energy consumption, the thermal regulation must present a good precision in the heating and cooling needs estimation. Therefore, the calculation model of this regulation was evaluated in relation to a dynamic simulation tool - VisualDOE. This evaluation was carried out applying both estimation methods to the Test Cells built in the School of Engineering of the University of Minho and the results obtained demonstrated a good performance of the thermal regulation.

1 INTRODUCTION

One of the main challenges that nowadays humankind has to face is the climatic changes and environmental depletion. It is known that these challenges are closely related to the energy consumption. In the 15 European Union, there are about 164 million buildings, responsible for 40% of the final energy demand and 1/3 of the greenhouse gas emissions. So, in order to promote the reduction of energy consumption, it is fundamental to apply sustainable development principles in the construction sector (Tzikopoulos et al, 2005; Eyckmans and Cornillie, 2002).

There are several measures that can be applied in order to reduce the buildings energy consumption, since the appeal of the consumers consciousness to the environmental problems, to the development of new construction solutions more energy efficient.

However, one of the measures with a larger impact in building energy consumptions is the implementation of more restrictive thermal regulation. The new Portuguese thermal regulation – Regulation of the Characteristics of the Thermal Behavior of Buildings (RCCTE) – increases the minimum requirements, promote the use of renewable energy and support the use of certified materials.

The driving force of the thermal regulation revision was the European Energy Performance of Buildings Directive (European Commission, 2003). The main objectives of the EPBD are the harmonization of all thermal regulations in the European Union and the increase of buildings energy performance, taking in account the climatic conditions, interior comfort of the occupants and economic viability, for both new buildings and existing buildings.

In order to be efficient and effective, the thermal regulation must correctly estimate the energy performance of buildings. Having this fact in mind the RCCTE calculation model was put side by side with the dynamic simulation for the energy performance estimation.

The case study was the heating and cooling needs estimation of the Test Cells built in the School of Engineering of the University of Minho, using the RCCTE calculation model and the dynamic simulation tool VisualDOE.

2 BUILDING DISCRIPTION

The Test Cells applied in this study are formed by a Sustainable Test Cell (STC), a Conventional Test Cell (CTC) and a Passys Test Cell (PTC). This study focuses on STC and CTC, in order to guarantee that the RCCTE can estimate with good accuracy conventional solutions and also non-conventional solutions.

2.1 *Sustainable Test Cell*

The Sustainable Test Cell (STC) contains two rooms:

- Room 1 (simulates a bedroom) – It was constructed using compacted earth walls (Goodhew & Griffiths, 2005) and an opening in the south façade. The high thermal inertia combined with an opening equipped with exterior horizontal and vertical shading devices to avoid overheating in the summer. In order to improve the sustainability of the solution the exterior walls of this room were built with a locally available material - Earth;
- Room 2 (simulates an office) – It is an insulated lightweight construction with a large opening in the north façade to promote daylightning and thus reduce the energy spent in lightning.

Between the two rooms of this Test Cell there is a movable partition that allows testing the performance of this Test Cell as a whole or as being constituted by two distinct rooms (Silva, 2006).

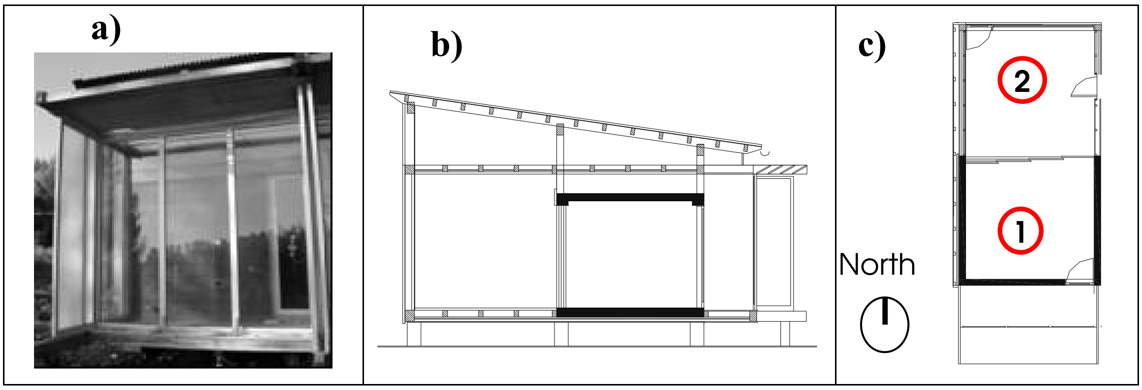

Figure 1. Sustainable Test Cell: a) Photo; b) lateral view; c) top view.

2.2 *Conventional Test Cell*

The Conventional Test Cell (CTC), shown in Fig. 2, contains three rooms: the room 1 simulates a bedroom; room 2 simulates a bathroom; room 3 simulates a hall. The CTC was built with a double pane hollow brick envelope wall with insulation on the air gap. This Test Cell represents the conventional Portuguese Construction (Mendonça, 2003).

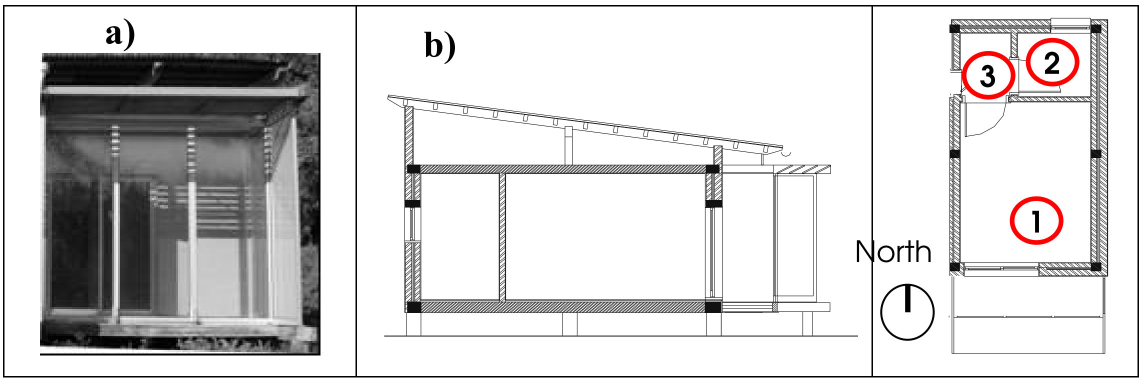

Figure 2. Conventional Test Cell: a) Photo; b) lateral view; c) top view.

3 ESTIMATION METHODS

3.1 *RCCTE*

The new Portuguese thermal regulation focuses residential buildings and service building without HVAC systems. One of the main updates in this regulation was due to the recent higher comfort required by the occupants, especially in terms of cooling demands. Then, the objectives of this regulation are: Guarantee that the heating and cooling requirements for thermal comfort, the ventilation requirements for air quality and the hot water requirements are satisfied without an excessive energy consumption; Minimize the pathologies in the construction elements due to condensation. The main updates in this regulation where (RCCTE, 2006):

- New climatic zoning;
- Interior comfort set points – Winter (20ºC); Summer (25ºC + 50% RH);
- Minimum air changes per hour – 0.6;
- Domestic Hot Water (DHW) reference consumption – 40 l at 60ºC per person and per day;
- New methodology for thermal bridges calculation;
- Heating needs methodology reviewed;
- New Cooling needs methodology;

This regulation defines reference values for the *primary energy global needs* (*Nt*) in order to limit the *specific nominal primary energy annual global needs* (*Ntc*). So, the *Ntc* value cannot be higher than the *Nt* value. The Nt and Ntc are obtained using the following equations:

$$\text{Nt} = 0{,}9.(0{,}01.\text{Ni} + 0{,}01.\text{Nv} + 0{,}15.\text{Na})\ (\text{kgep/m}^2.\text{year}) \quad (1)$$

Where *Ni, Nv, Na* are the heating, cooling and DHW reference needs, respectively.

$$\text{Ntc} = 0{,}1.(\text{Nic}/\eta\text{i}).\text{Fpui} + 0{,}1.(\text{Nvc}/\eta\text{v}).\text{Fpuv} + \text{Nac.Fpua}\ \ (\text{kgep/m}^2.\text{year}) \quad (2)$$

Where *Ni, Nv* are the heating and cooling system efficiencies, respectively; *Nic, Nvc, Nac* are the heating, cooling and DHW specific needs, respectively; *Fpui, Fpuv, Fpua* are the weighting factors for the heating, cooling and DHW needs, respectively.

3.2 *VisualDOE*

VisualDOE is a Windows™ application that can estimate the energetic performance of buildings. The calculation engine used in this tool is the, very well known and tested, DOE2.1E. However, only the 3rd version of this tool (VisualDOE 3.1) can be considered as a Graphical User Interface of the DOE engine, as it allows a good control of the introduction of geometrical elements, in real-time, thru the visualisation of the model produced by the tool and it has the possibility to edit the model by simply clicking with the mouse in a element. This tool can be used without any knowledge of the source engine (Green Design Tools, 2001).

For estimate the buildings energy performance with VisualDOE it is necessary to follow 3 steps:

- Project data introduction;
- Execution of the simulation;
- Results analysis.

The project data introduction begins with the definition of all the VisualDOE databases with the elements applied in the building – Glazing, Openings, Materials, Constructions, Occupancy, Schedules and Utility rates – and afterwards the introduction of the model and project data that is formed by 6 folders – Project, Blocks, Rooms, Façade, Systems, Zones. As VisualDOE was created for the Windows™ platform, the databases are easily updated with new material and constructions thru a graphical interface, as shown in Figure 3.

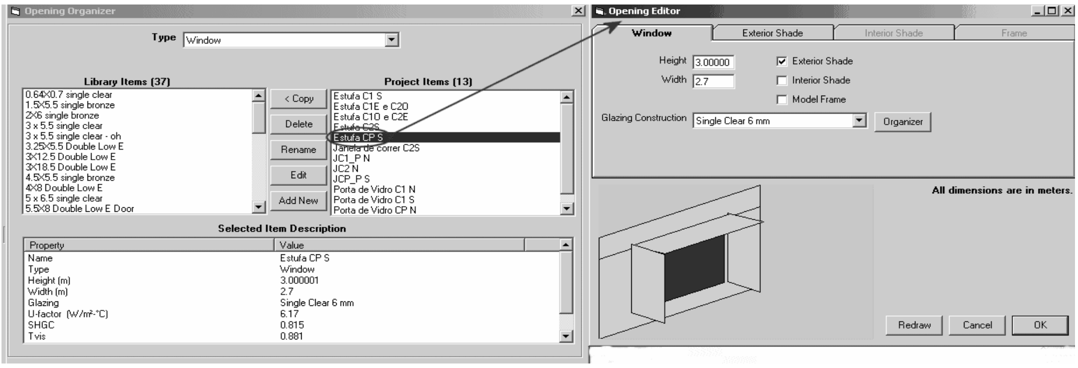

Figure 3. Openings definition in VisualDOE databases.

In the 2nd step there will be present three folders – Simulation, Standard DOE-2 Reports and Hourly Reports – where the user can define the base case, the alternatives (if necessary) and all the reports needed (hourly, daily, monthly or yearly results) for each specific study.

For the results analysis there are two main groups of data – the VisualDOE graphs and reports and the DOE-2 reports. The main difference between these sets of results is that the ones obtained by VisualDOE follow the Windows™ platform (allows exporting results to other tools) while the DOE-2 reports follow a DOS platform.

3.3 *Model Calibration*

To guarantee a good accuracy of the model, it is necessary to calibrate it, adjusting the model to the reality. In this Case Study the calibration was possible due to the existence of a measurement system in the Test Cells and it was carried out in three main steps (Silva et al, 2006):

- Obtaining a climatic file that represent the climatic conditions which the Test Cells were exposed;
- Obtaining the "in-situ" thermal resistance of the exterior walls;
- Comparing the interior temperature, measured "in situ" with the interior temperature calculated by VisualDOE.

Climatic File – For this case study the climatic file was obtained using the data retrieved from the weather station installed in the Test Cells. However, in addition to the parameters directly obtained by the weather station it was necessary to calculate more parameters (underlined in Table 1) using the ones obtained "*in-situ*" (ASHRAE, 1997; Buhl, 1999; ISQ, 2000; Krieder and Rabl, 1994).

Table 1. VisualDOE required climatic data.

"In-Situ" Parameters	Required Parameters	Obtained from:
1) Temperature	Dry bulb Temperature	1)
2) Relative Humidity	Wet bulb Temperature	1); 2)
3) Precipitation	Humidity Ratio	1; 2)
4) Wind Direction	Enthalpy	1); 2)
5) Wind Speed	Precipitation	3)
	Wind Direction	4)
6) Total Horizontal Solar Radiation	Wind Speed	5)
	Total Horizontal Solar Radiation	6)
	Direct Solar Radiation	6)
	Clarity ratio	6)

"In-situ" thermal resistance – The method used for the calculation of the "*in-situ*" thermal resistance of exterior elements was the sum technique from the ASTM Standard C1155–95 (ASTM, 1999). With this method it was necessary to obtain the heat flux (q_i), interior an exterior superficial temperature (T_{is}, T_{es}, respectively). Then, the thermal resistance is obtained by the Equation 3:

$$R_e = \frac{\sum_{k=1}^{M} \Delta T_{Sk}}{\sum_{k=1}^{M} q_{ik}} \tag{3}$$

However, to guarantee a good performance of the calculation it is necessary to execute a convergence test (CR_n), where two consecutive time intervals must have a convergence lower than 0.1, and a variance test [$V(R_e)$] where the variance must be lower than 10%.

The thermal resistances of the Test Cell elements identified in Figure 4 were obtained by the use of this technique and the respective values are:

Wall A – Compacted earth, 15 cm; *Thermal Resistance* - **0.34** m^2.ºC/W;

Wall B – Agglomerated board (concrete / wood), 1.2 cm + Air layer, 4 cm + Expanded cork insulation, 5 cm + Compacted earth, 15 cm; *Thermal Resistance* - **2.97** m^2.ºC/W;

Wall C – Agglomerated board (concrete / wood), 1.2 cm + Air layer, 6 cm + Agglomerated board (concrete / wood), 1.9 cm + Expanded cork insulation, 8 cm + Coconut fiber insulation, 2 cm + Carton / plaster gypsum board, 1.3 cm; *Thermal Resistance* - **1.04** m^2.ºC/W;

Wall D – Stucco, 2cm + Hollow brick, 11 cm + Air layer, 4 cm + Extruded Polystyrene insulation, 4 cm + Hollow brick, 15 cm + Stucco, 2cm; *Thermal Resistance* - **0.34** m^2.ºC/W.

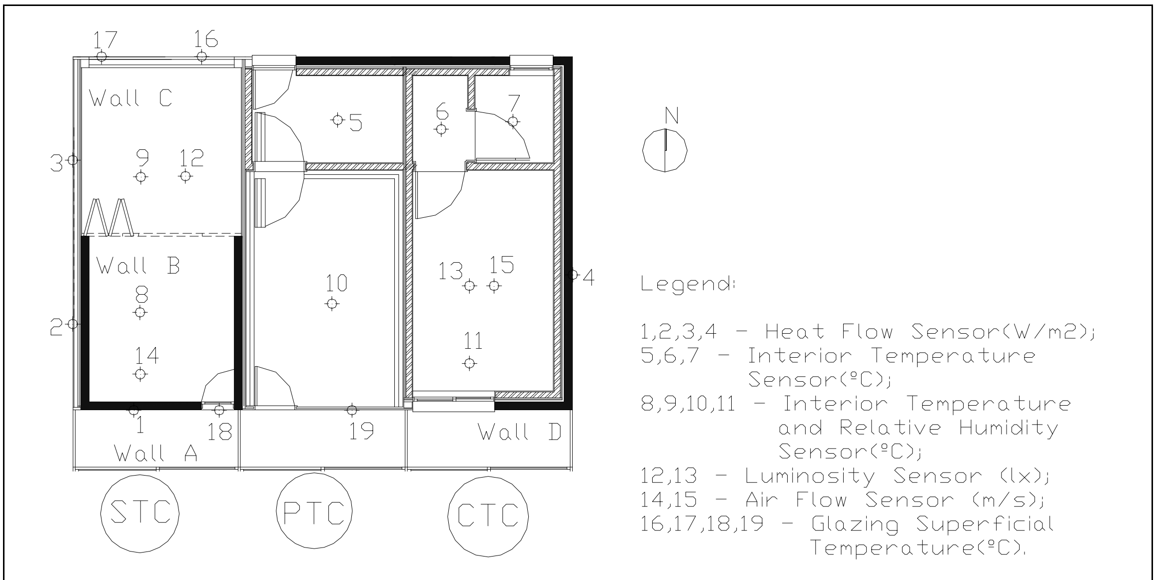

Figure 4. Distribution of sensors inside the Test Cells.

"In-Situ" temperature Vs VisualDOE calculated temperature – This procedure is very useful for making the last adjustments of the model, being possible the detection of some inaccuracy in the model as well as adjusting the thermal inertia. In Figure 5 it is possible to observe the results from the model adjustments.

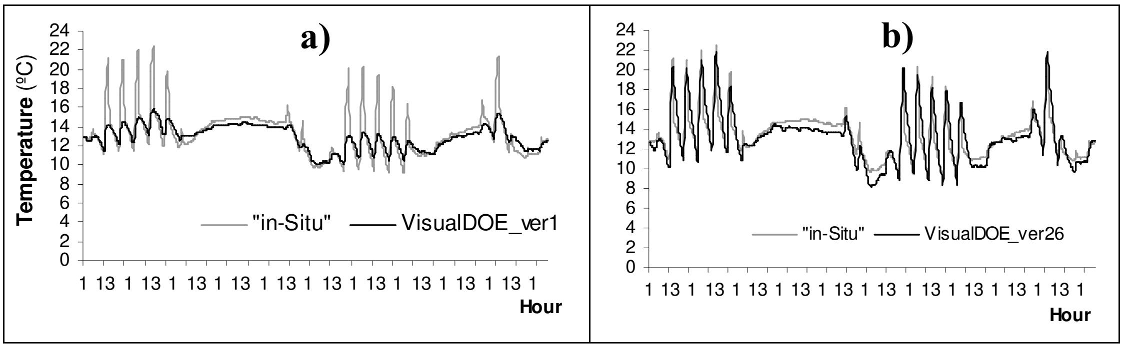

Figure 5. CTC interior temperature in VisualDOE model: a) before calibration; b) after calibration.

After the model calibration, the average error of the model was tested comparing the "*in-situ*" measured Test Cells interior temperature with the VisualDOE results, for the whole period of the simulation – October 2003 to October 2004. Between October 2003 and February 2004, the Test Cells were not equipped with the Sunspace (built in March 2004), and thus the model of the Test Cells without sunspace was tested for an average error between October 2003 and February 2004. The model with sunspace was tested for the remaining period.

The average error of the model without sunspace is of 8% and for the model with sunspace is of 4.8%. Taking into consideration that the obtained average errors are relatively small and that the calibration was performed for one year of "*in-situ*" measurements, the achieved results assure that the application of VisualDOE is representative and thus it is possible to use it to test the energetic performance of the Test Cells.

4 RESULTS

4.1 *RCCTE*

To achieve better results using the simplified model RCCTE, was necessary to calibrate some parameters specifically to this case study. Then, the Degree-Days, the average monthly solar energy and the summer average temperature, were calculated from the Test Cells weather station data instead of using the standard values tabulated in the thermal regulation.

Also, for the walls to which the "*in-situ*" thermal resistance was calculated the respective values were applied in the RCCTE.

Following the thermal regulation methodology to the CTC and the PTC it was obtained the result shown in Table2.

Table 2. Heating and Cooling need from RCCTE.

Test Cells		Heating Needs	Cooling Needs	Total Needs
			(kwh/m^2.year)	
With Sunspace	STC	127.7	49.5	177.2
	CTC	100.9	13.8	114.7
Without Sunspace	STC	139.8	51.3	191.1
	CTC	129.4	30.3	159.7

4.2 *VisualDOE*

After the calibration of the Test Cells model, the entire project data was inserted in VisualDOE and a "warming" simulation was carried out being created an Input file to the DOE-2 calculation model. This Input file was modified to allow the introduction of all the particularities of the Test Cell, as the introduction of some construction materials, the modification of some construction elements in the interior walls, floors and roofs, the definition of the sunspaces, the modification of the thermal inertia. Then, the Test Cells VisualDOE final model (Figure 6) was created and became ready to be used.

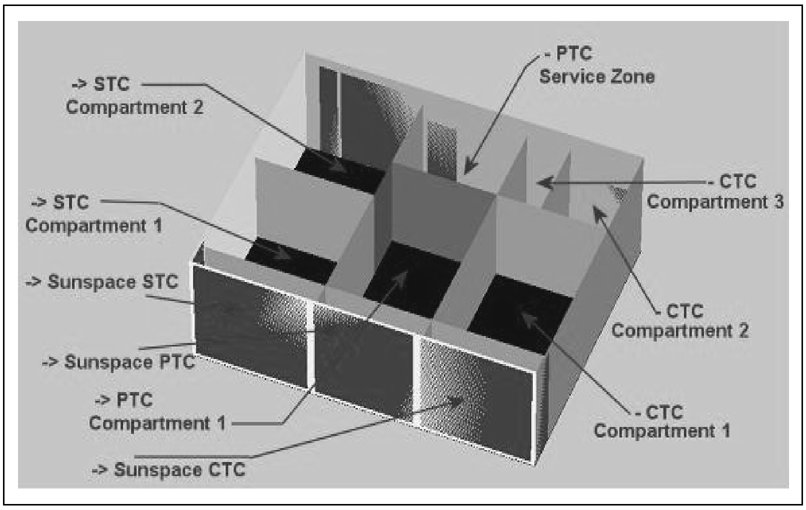

Figure 6. Model of the Test Cells.

In order to run the final simulation, it was inserted the final model in VisualDOE and defined a HVAC system with the heating and cooling setpoints as established in RCCTE – 20ºC for heating and 25ºC and 50% RH for cooling. For the final reports it was selected the hourly energy consumption spent by the HVAC system. The results obtained are presented in Table 3.

Table 3. Heating and Cooling need from VisualDOE.

Test Cells		Heating Needs	Cooling Needs	Total Needs
			(kwh/m^2.year)	
With Sunspace	STC	124.7	41.9	166.6
	CTC	120.5	13.6	134.1
Without Sunspace	STC	135.2	42.5	177.7
	CTC	149.8	32.3	182.1

4.3 *RCCTE Vs VisualDOE*

In order to test the precision of the RCCTE calculation methodology the results obtained where compared with the ones obtained by VisualDOE (the heating and cooling needs obtained from VisualDOE were calculated only for the periods defined in RCCTE as heating season and cooling season). The differences between the two estimation methods are presented in Table 4.

Table 4. Difference between RCCTE and VisualDOE estimation.

Test Cells		Heating Needs	Cooling Needs	Total Needs
			Differences (kwh/m^2.year)	
With Sunspace	STC	3	7.6	10.6
	CTC	19.6	0.2	19.4
Without Sunspace	STC	4.6	8.8	13.4
	CTC	20.4	2	22.4

From Table 4 it can be concluded that there is an unexpected very high convergence between the STC total needs estimated by RCCTE and by VisualDOE, with only an average variance of 6.5% in the total needs. This fact is due to the good calculation methodology adopted by RCCTE in association with the accurate calibration of the models. The higher variation in the estimation of CTC total needs, 13.4%, is due to the heating needs part. This fact can be explained by a higher south oriented glazing area in this Test Cell that can lead to very high solar radiation entering the building. This inaccuracy can lead to an overestimation of the thermal gains in the RCCTE methodology.

5 CONCLUSIONS

The objective of this study was to evaluate the precision of the new Portuguese thermal regulation calculation methodology. Therefore, the RCCTE heating and cooling needs estimation was put side by side with the ones calculated with the dynamic simulation tool VisualDOE.

From this evaluation it can be said that the RCCTE calculation methodology have a better precision than what was expected, as it is a simple method based in the Degree-Day method. This method just appears to have a higher difficulty in estimate accurately the heating needs for buildings with large openings.

Then it can be assumed that this new regulation can estimate the buildings energy needs accurately and thus it can be used as a simplified tool to evaluate the energy efficiency of buildings.

6 REFERENCES

ASHRAE, 1997. Handbook of Fundamentals, Atlanta: American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

ASTM, 1999. Standard Practice for Determining Thermal Resistance of Building Envelope Components from the In-Situ Data. Standard C 1155 - 95. Annual Book of ASTM Standards, Volume 04.11, West Conshohocken.

Buhl, 1999. DOE-2 Weather Processor. LBNL Simulation Research Group.

European Commission, 2003. Directive 2002/91/EC of the European Parliament and of the Council. Official Journal of the European Communities: 65-71.

Eyckmans, J. & Cornillie, J.2002. Efficiency and Equity in the EU Burden Sharing Agreement. Katholieke Universiteit Leuven, Centrum voor Economische Studiën, Energy, Transport and Environment.

Goodhew, S. & Griffiths, G. 2005. Sustainable earth walls to meet the building regulations, Energy and Building 37: 451-459.

Green Design Tools, 2001. VisualDOE 3.0 Program Documentation. San Francisco: Eley Associates.

ISQ, 2000. Térmica dos Edifícios, Oeiras: Instituto de Soldadura e Qualidade.

Krieder, J. & Rabl, A. 1994. Heating and Cooling of Buildings - Design for Efficiency, Mechanical Engineering Series. McGraw-Hill International Editions.

Mendonça, P. 2005. Habitar sob uma Segunda Pele: Estratégias para a Redução do Impacto Ambiental de Construções Solares Passivas em Climas Temperados. Doctorate Thesis. University of Minho. Guimarães.

RCCTE – Regulamento das Características do Comportamento Térmico dos Edifícios, 2006. Decreto-Lei nº 80/2006 de 4 de Abril, Ministério das Obras Públicas, Transportes e Comunicações.

Silva, P. 2006. Thermal performance evaluation of non conventional constructions through simulation in VisualDOE. Masters Thesis. University of Minho. Guimarães.

Silva, P., Mendonça, P., Bragança, L. and Almeida, M. 2006. Sustainable Test Cell – Performance Evaluation, Proceedings of Healthy Buildings 2006, June 4-8, Lisbon, vol. 5: 247-252.

Tzikopoulos, A.F., Karatza, M.C., Paravantis J.A. 2005. Modeling energy efficiency of bioclimatic buildings, Energy and Building 37: 529-544.

Local actions to improve the sustainable construction in Italy

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ABSTRACT: Evolution of environmental sensitivity and spreading of the consciousness of a socially sustainable common acting, economically and technologically, supported by the acknowledgment of a few European and domestic laws, led to definitions of a few local normative tools for the preliminary definition and control of building activity in energy and environment vision. The current experimentations highlight as to make sure that the sustainable building becomes a diffuse and constant practice it is necessary, by the local governments, a deep revision of the methodologies up to today adopted as usual general procedures and in the editing of the urban and implementing planning tools.

1 INTRODUCTION

"Buildings and the built environment are the defining elements of the urban environment. They give a town and city its character and landmarks that create a sense of place and identity, and can make towns and cities attractive places where people like to live and work". (COM(2004)60 final). The local governments of Italian Regions, Provinces and Cities laboriously and starting from the nineties have begun to take conscience of the necessity of promoting environmental policies turned to the improvement of living conditions of citizens and to the mitigation of the building and productive activities effect on the urban ecosystem, often already compromised.

Evolution of environmental sensitivity and spreading of the consciousness of a socially sustainable common acting, economically and technologically, supported by the acknowledgment of a few European and domestic laws, led to definitions of a few local normative tools for the preliminary definition and control of building activity in energy and environment vision.

These normative tools, accepting national indications above all in terms of energy performance of buildings and therefore on energy management of the building activities, are going over the traditional approach to the direction of building activity based on the static safety check of the healthiness, of the analytical control of dimensional parameters.

Local regulation (building regulations, technical rules, regional guidelines, etc.) aim to lead individual choices to collective interests, which can find either obstacle or agreement in the individual actions.

Taking into consideration that the environmental load of the building factor on the global environmental balance of human activities, that 80% of European citizens live in urban territory spending around 90% of their time inside buildings, it gets across as the inclusion of issues pertaining sustainable construction represent a recall to the public and private clients structures to the reply to a new more structured and mature demand system expressed by the citizens, both in implicit and clear way.

Sustainability proposes itself as value added to local government actions, but also as economic surplus in setting-up the market exchange of a building.

The new requirement framework outlined with respect to building activities, related to construction of both residential buildings and edifices for the tertiary industry, express a request for quality connected to the transformation of the buildings utilisation model.

In particular this renewal is more perceivable in the residence where the traditional utilisation model has been deeply put under discussion by many factors; the new working behaviours, the presence of the working activities in domestic location, the internal cohabitation of spaces of the traditional residential activities with those of spare time and recreation, the presence of a significant share of sophisticated IT technologies until some year ago foreign to the domestic environment have deeply changed and made more complex the guide requirement system for the building design.

Where previously the environment healthiness had to be and could be only ensured through the building orientation control and the indoor air quality check, today it must be evaluated also depending on density and on distribution of the equipments networks inside the building.

Even if this kind of controls of building environmental impact is a definitely a positive action, the poor coordination at a national level of the different initiatives can cause some inconvenience in terms of harmonization of promoted measures and of driven effect control, causing also a certain disorientation between the sector operators.

1.1 *Action levels*

Levels of actions of the policies oriented to the sustainability in construction are essentially three: regional, provincial and municipal; these three action levels reproduce levels of management of territory administration and building activities.

Regional governments give indications of behaviour of general interest and technical sector specifications, for the sectors of their specific pertinence (social housing, health, education, etc), Provinces have a very important role in the policies of specific sectors especially on house and on education, while Municipalities give building technical indications turned to the realization of the whole building stock, independently of the destination, and exercise also the control function during realization and inspection.

Actions proposed by various bodies are appropriate to their fields and intervention levels in the management of the building activity.

Normative actions undertaken from several administrations represent all actions aimed at the promotion of a culture and of a diffuse practice in sustainable construction; the sustainable approach requires in fact a concrete and deep change in practices and in behaviours of all the operators of the building process, in urban planning, in new public and private constructions and in the building refurbishment operations.

In this process of innovation of planning and accomplishing behaviours, Public Administrations and, in particular, Local Government, to which is entrusted the direction and control role in the process of territory transformation, must become promoters and virtuous behaviour model in a sustainable vision.

To local governments is entrusted the task to identify the best practice to be submitted to the building operators for the realization of their construction initiatives. This kind of actions requires a big planning effort by the local governments, called to test new ways of prefiguration of the behaviours of process actors, being obliged to go away from the traditional building rule prescriptive-generalist usually without those contents performance kind, useful also to the efficiency and effectiveness check of some proposed planning solutions or of some technical solutions put in practice from the executors.

1.2 *Evolution of a territory and towns government culture. Exemplary cases.*

Strategic role in the building sector cultural renewal is played by Regional government. Its work on definition of guidelines on control and government of construction activity contains in fact all the features of the total strategic approach which allows, in the subsequent action levels, to fine-tune a policy of integrated approach to the man-made environment transformation from a sustainable point of view.

It is important to point out that in almost every case the introduction of a system of rules of promotion of indications or prescriptions on the construction sustainability has not overturned the traditional structure of sector regulation.

In many cases the introduction of sustainability criteria or best practices oriented to the realization of sustainable buildings supports indications and traditional prescriptions defining a new quality profile, more complex and effective in terms of environmental impact, wealth of users and reduction of the energy use.

The document of the Emilia Romagna region which defines criteria for editing of building code to be used by the Municipalities of his territory is paradigmatic of this type of behavior. In this case the building activity regulation is based on the building conformity to two requirements families, one that is the binding family of requirements, the Compulsory requirements, the other that is the voluntary family, the Suggested requirements later updated in contents and aims and changed in Voluntary requirements, concerning wealth and usability of construction works.

This requirements package aims to improve the life quality of the users according to the ecosystem receptive capacity, to the possibility of natural resources renewal and to the balance between anthropic systems and natural systems. Information related to interactions between building and environment to reduce the not renewable energy consumption and for the CO2 emission reduction in atmosphere are taken in great consideration.

The structure given to the orientation action of the Region prefigures a hierarchical articulation of the instructions given on the building activity; compulsory requirements give directions on safety, stability and healthiness of buildings and on way to meet general requirements of energy saving, acoustic isolation on the space usability. The voluntary requirements define an area of performance surplus value of the buildings; these define directions on damaging discharge, superficial humidity, artificial lighting, air temperature and speed, acoustic isolation and wiring installation. The suggested voluntary requirements define an additional quality of the building product, which the administration makes attracting from an economic point of view for the promoter through discounts on the urbanization burdens.

The line traced by the Emilia Romagna Region has been followed also by other administrations which have always articulated their regulation activities distinguishing between compulsory prescriptions and rewarding indications always identifying the environmental quality and the sustainability of the interventions among the rewarded behaviors, however consolidating the perception of "value added" for the environmental sustainability of constructions.

Recent rules on buildings energy performance, implementation of 2002/91/CE directive, and consequent effects on the management of building activities, will probably compete in creating a consciousness also of the economic value added given by the best energy performance of the building; this side effect could work as lever to trigger a virtuous behavior also at level of compounds and not only of single building, involving not only the energy consumptions evaluation, but also evaluation on comfort of the users, production of harmful substances and waste, and on the rationalization of water resources use.

This is the case of the Municipality of Rome which in 2006 has given off a measure which supplemented with the its building rule with specific directions for the realization and promotion of environmental improvement intervention, for the use of alternative energies focusing on solar energy, for the use of optimum materials, components and adequate systems to reach levels of thermal isolation and thermal building covering inertia, as well as assuring the deep soil permeability also in urban area. The way chosen by the Municipality of Rome has not been the way of the voluntary compliance to these indication, but the one of forcing to specific prescription, therefore turning to quantitative and not performance indications.

This regulation follows the indications already contained in the technical rules of new general town planning scheme (Piano Regolatore Generale), with which those have been included between the acceptable intervention categories of bio-energetic improvement (MBE), that is the set of interventions turned to improve the bioclimatic performances of man-induced elements. These interventions include the climatic regulation and protection or acoustic recovery of the buildings, according to principles of bio-architecture, preservation of deep soil permeability, use of natural and renewable energy sources, waste and meteoric water recovery for irrigation uses, soil fertilization or hygienic services, use of lasting and maintenanceable building materials, use of the green with aim of microclimatic regulation and protection from the acoustic and atmospheric pollution. To this measure the Municipality has associated a rewarding system of incentive to encourage private promoters to take charge of these actions, granting a surplus of cubature to compensate any additional investment to set up their realization.

Another kind of methodological approach, that moreover corresponds to an intermediate territory government action level, is what has been realised by a few provinces. The case of the Province of Lecco is representative of this approach. The province has elaborated a package of "Guide lines for the promotion of the sustainable development in the territory government tools and in the building regulations", which starting from the local energy programming describe the recourse to tools and strategies aimed to the promotion of sustainability in territorial, urban and construction planning.

The description of best practices aiming to show to local governments how to behave for the Sustainability Promotion on the territory is part and parcel of these guidelines, describing in particular the measures of accompanying which many administrations have already implemented successfully; also in this case, incentive measures of different kind are taken into considerations.

Indication to set local Building Rule is given in this case according to actions/requiremens guide of which the application is stated as compulsory or voluntary and described in performance terms to make the application easier by the various administrations.

This is very nimble document and appropriate to be used by the administrations, being built in a very effective way; the identified action levels are only seven and their implementation is delegated to the Municipalities which will undertake the indications. Action levels concern site analysis, soil use and outside environment quality, internal environment quality, materials and technologies, coherent use of climatic and energy resources, rational use of water resources, quality of management.

Another interesting experience is the one of the Itaca protocol for the evaluation of energy and environmental quality of a building. This document is the result of the action taken by a national workgroup composed by representatives of all the Regions, in which APAT (Agency for environment protection and technical services) has also taken part, established in January 2002 at the office of Itaca (National association for the innovation and the transparency of the contracts and for the environmental compatibility).

The result of the workgroup activity is a protocol of shared work which allows to attribute an eco-sustainability score to a building, but above all, with the protocol adoption a shared unambiguous method of assessment of constructions sustainability has been uniquely defined.

The protocol is composed by seventy cards of evaluation, one for each environmental compatibility requirement. Cards include informative element, such as normative and technical references and the weight to be given to any requirement. The reference matrix is GBTool. Building environmental cross-compliance evaluation criteria used by the system have been structured and codified in areas of evaluation, which in their turn are composed by many performance subrequirements. Also the score attribution system is borrowed by GBTool, but with the possibility, for every administration, of customize the weight of every individual requirement to fit it to its local needs.

Many administrations are already referring to this document, between the other ones the Tuscany Region which has put beside this methodology adopted for the draft of the "Guidelines for the sustainable construction in Tuscany" also a " Basic list of materials for sustainable construction", document which represents a support tool for designers and administrations for the conscious choice of technical solutions for the building realization.

The case of the City of Torino probably represents an evolution of this operative culture. The City of Torino, in addition to having recently rewritten his Building Code (2004-2006), has faced for the realization of the structures necessary for the winter Olimpyc Games of 2006, a big investment phase on planning and control on building activity both for residential buildings and for facilities and infrastructures. This preliminary planning engagement has produced, between the other, series of tools which have been useful to design and realization control of these works; between these tools is to be considered in particular “Strategic Environmental Evaluation (Vas) of the intervention planning for the Winter Torino Olympic Games 2006”, which in addition of providing general indications for the phases of activation of the Olympic Program has formulated prescriptions for the processing of the projects of the Olympic works, and the "Guidelines for sustainability in project, in building and in management of the Olympic villages and Multimedia".

These documents represent some tools of strategic programming specific for this activity and not documents of general interest for the City, but given the level of effects and size of the works on the municipal territory, they are an important precedent in town building practice. Many of the indications elaborated in these documents have been then taken by the regulations issued later by the Minicipality, in particular indications concerning energy management.

"Guidelines for sustainability in project, in building and in management of the Olympic villages and Multimedia" issued from Environment Park in cooperation with experts of the Polytechnic of Torino, are an operating tool, addressed both to subjects in charge of the management of the Olympic program and to the Olympic Villages works planners. The structure of the guidelines is directed to facilitate their application and then make easier the reaching of the objectives. In fact, besides the environmental quality requirements, also the most appropriate technologies are shown, together with the normative references, the indicators and the tools to verify the satisfaction during project, building and use. For the first time all the fundamental requirements are synthesized and quantified in a single document to characterize the energetic-environmental quality of a building. This document result from the politic-strategic will of the promoter committee to place the promotion of the sustainable development, also taken ahead through this document, like a fundamental objective of the Olympic Movement, as clearly affirmed in the CIO diary 21.

"Guidelines for sustainability in project, in building and in management of the Olympic villages and Multimedia" were developed taking these principles into account, therefore aiming to obtain, in the realization of the building works foreseen by the Olympic Program, concrete results for a more sustainable built environment.

1.3 *Conclusions*

The short view given above, while testifies a slow evolution of the culture of building activity government and of the territory government, also testifies of the amount of road that the Italian reality still has to cover to relate the behavior of local governments which manage the territory at an acceptable level in terms of sustainability. The current experimentations highlight as to make sure that the sustainable building becomes a diffuse and constant practice it is necessary, by the local governments, a deep revision of the methodologies up to today adopted as usual general procedures and in the editing of the urban and implementing planning tools.

These tools will have to always assume the guide role into the design process, in order to lead to the configuration of an idea of city in which the sustainable construction is not only the current episodic value added of a few special opportunities, but the current practice.

All the described experiences can represent the starting point for the consolidating of this culture and practice.

REFERENCES

ADEME - Agence de l'Environnement et de la Maîtrise de l'Energie, 2003. *Qualitè Environnementale des Bâtiments. Manuel à l'usage de la maîtrise d'ouvrage et des acteurs du bâtiment,* Paris: ADEME

APAT Agenzia per la protezione dell'ambiente e per i servizi tecnici, 2005. *Qualità dell'ambiente urbano – II Rapporto APAT*, Roma: APAT

APAT Agenzia per la protezione dell'ambiente e per i servizi tecnici, 2006. *Qualità dell'ambiente urbano – III Rapporto APAT*, Roma: APAT

Battisti, A., Tucci, F. 2002, *Qualità ed ecoefficienza delle trasformazioni urbane,* Firenze: Alinea

Battisti, A., Tucci, F., 2000. *Ambiente e cultura dell'abitare. Innovazione tecnologica e sostenibilità del costruito nella sperimentazione del progetto ambientale*, Roma: Dedalo

Calvi, G. (ed.), 2002. *Progetto qualità edilizia: 1922-2002,* Pavia: ALER Pavia, Azienda lombarda per l'edilizia residenziale della provincia di Pavia, Edizioni Edilizia Popolare

Commission of yhe Council The European Parliament, 2004. *COM(2004)60 final Communication from the Commission of yhe Council The European Parliament, tha European Economics and socila committee and the committee of the Regions, Towards a thematic strategy on the urban environmen*t, Bruxelles: Commission of yhe Council The European Parliament

Commissione Infrastrutture mobilità e governo del territorio della Conferenza delle Regioni e delle Province autonome, 2007. *Opportunità di coordinamento per la ricerca di obiettivi condivisi tra le Re-*

gioni per lo sviluppo sostenibile nell'edilizia, Roma, 8 marzo 2007
Comune di Carugate - Provincia di Milano. 2003. *Regolamento edilizio.* Carugate: Comune di Carugate
Comune di Correggio. 2006. *Regolamento Edilizio Comunale. Requisiti energetici degli edifici.* Correggio: Comune di Correggio
Comune di Ferrara. 1998-2006 *Regolamento edilizio del Comune di Ferrara*. Ferrara: Comune di Ferrara
Comune di Reggio Emilia - Assessorato Urbanistica ed Edilizia. 2006. *Architettura Sostenibile: risparmio e qualità nell'edilizia. Allegato al Regolamento Edilizio Comunale*. Reggio Emilia: Comune di Reggio Emilia
Comune di Rimini. 2005. *Misure Volontarie in Bioedilizia. Allegato al Regolamento edilizio Comunale*, Rimini: Comune di Rimini -Settore Ambiente e Sicurezza
Comune di Rimini. 2005. *Relazione illustrativa alle Misure Volontarie in Bioedilizia. Allegato al Regolamento edilizio Comunale*, Rimini: Comune di Rimini -Settore Ambiente e Sicurezza
Comune di Roma. 1934 – 2006. *Regolamento generale edilizio delCcomune di Roma*.Delibera 18.8.1934 n. 5261, Roma: Comune di Roma
Comune di Roma. 2006. *Variazioni ed integrazioni al vigente testo del Regolamento Edilizio Comunale. Norme per il risparmio energetico, l'utilizzazione di fonti rinnovabili di energia e risparmio delle risorse idriche.*. Delibera 20.2.2006 n. 48, Roma: Comune di Roma
Comune di Roma.2006. *Norme Tecniche di Attuazione. Testo integrale coordinato con le modifiche introdotte in sede di controdeduzioni,* Roma*:* Comune di Roma. Dip VI - Politiche della Programmazione e Pianificazione del Territorio – Roma Capitale U.O. n .2 Ufficio Pianificazione e Progettazione Generale
Comune di Torino. 2004. *Regolamento edilizio dela Città di Torino*, Torino
Comune di Torino. 2006.*Allegato energetico-ambientale al Regolamento edilizio dela Città di Torino*, Torino
Decreto Legislativo 19 agosto 2005, n. 192 "Attuazione della direttiva 2002/91/CE relativa al rendimento energetico nell'edilizia". Gazzetta Ufficiale n. 222 del 23 settembre 2005 – S.O. n. 158
Decreto Legislativo 29 dicembre 2006, n. 311 "Disposizioni correttive ed integrative al decreto legislativo 19 agosto 2005, n. 192, recante attuazione della direttiva 2002/91/CE, relativa al rendimento energetico nell'edilizia". Gazzetta Ufficiale n. 26 del 1 febbraio 2007 – S.O. n. 26/L
Dierna S., Orlandi F. 2005, *Buone pratiche per il quartiere ecologico. Linee guida di progettazione sostenibile nella città della trasformazione*, Firenze: Alinea
Environment Park. 2001. *Linee guida per la sostenibilità nel progetto, nella costruzione e nell'esercizio dei Villaggi Olimpici e Multimedia,* Torino*:* Environment Park – Torino 2006
European Parliament. 2002. *Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.* Bruxelles: European Parliament
European Parliament. 2002. *Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.* Bruxelles: European Parliament
Grosso M., Peretti G., Piardi S., Scudo G. 2005. *Progettazione ecocompatibile dell'architettura. Conectti e metodi, strumenti d'analisi e valutazione, esempi applicativi*, Napoli: Sistemi editoriali
I.M.B.E.- Institut Méditerranéen du Bâtiment et de l'Environnement; ADEME - Agence de l'Environnement et de la Maîtrise de l'Energie. 2004. *«HQE® Aménagement» International, Rapport Final*, Paris: I.M.B.E. - ADEME
ITACA - Associazione nazionale per l'innovazione e la trasparenza degli appalti e per la compatibilità ambientale. 2004. *Protocollo ITACA per la valutazione della qualità energetica ed ambientale di un edificio*, Roma: ITACA
Lepore M. 2004. *Progettazione bioclimatica in ambito urbano*, Roma: Aracne
Lucarelli M.T. (a cura di) 2006. *L'ambiente dell'organismo città. Strumenti e sperimentazioni per una nuova qualità urbana*. Firenze: Alinea
Provincia di Milano. 2006. *Linee Guida per la Progettazione e Requisiti Prestazionali di controllo della qualità del manufatto edilizio*. Milano: Provincia di Milano
Provincia di Pavia. 2006. *Linee Guida per la definizione di un Regolamento edilizio di tipo Provinciale*. Pavia: Provincia di Pavia – Settore Risorse Naturali UOC Aria Energia
Raspar A., Santonico D. 2005, Elementi di edilizia sostenibile. Progettare e costruire in sintonia con l'ambiente, in APAT Agenzia per la protezione dell'ambiente e per i servizi tecnici, *Qualità dell'ambiente urbano – II Rapporto APAT*, Roma: APAT: 579-620
Regione Emilia Romagna, 2000. *Requisiti volontari per una qualità ambinetale degli interventi edilizi. Relazione tecnica,* Bologna: Regione Emilia Romagna
Regione Lazio. 2004. *Legge Regionale n.15 del 8-11-2004 "Disposizioni per favorire l'impiego di energia solare termica e la diminuzione degli sprechi idrici negli edifici"* (B.U.R. Lazio n. 31 del 10.11.2004), Roma: Regione Lazio
Regione Toscana, 2005. *Linee guida per la valutazione della qualità energetica ambientale degli edifici in Toscana, Firenze:* Regione Toscana

Regione Toscana, 2005. *Elenco base dei materiali per l'edilizia sostenibile, Firenze:* Giunta Regionale Toscana - Direzione Generale della Presidenza - Area di Coordinamento Programmazione e controllo - Settore Programmazione dello Sviluppo Sostenibile

SACERT. 2006. Certificazione energetica degli edifici. Procedura operativa e Modello di Calcolo. Milano: SACERT – Provincia di Milano

SHE Sustainable Housing in Europe. 2003. State of Art of Italy, Roma: SHE

Szokolay, S. 2004, *Introduzione alla progettazione sostenibile*, Milano, Hoepli

Zito V. 2001. Recenti orientamenti delle regioni in materia di Regolamenti edilizi. in *Per un nuovo Regolamento edilizio - Seminario di studi - Bari, 30 maggio 2001, CNR - ITC Istituto per le Tecnologie della Costruzione*, Bari: CNR

Zito V. 2006. Il Contributo degli Enti Locali nella progettazione edilizia sostenibile in *L'Ufficio Tecnico*, Rimini, Maggioli

Alternative network geometry of essential networks for enduring sustainable development

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ABSTRACT: The technical infrastructure (networks) of the essential flows (energy and sanitation, i.e. water, waste) is determinative to what degree a project, varying in scale from a (part of a) building to a city or conurbation, will or can be sustainable or even self-sustaining. This is due to its 'path-dependency', long term- and endogenous character and the existence of a limited number of dominant actors per network or flow, which have interest in little change of the 'ruling' paradigms. The physical and formal distance to users and the complexity for them to understand the processes and possible (sustainable) alternatives result in an increasing dependence (heteronomy) and a declining overall involvement. To be able to change the built environment in accordance with the principles of sustainable development there is a need to turn around the inter-relationship between the infrastructure and the suprastructure. Decisive aspects in a continuing urbanizing, and connected world with crucial dependency on integrated computer networks, will be the flexibility of the concept of generation, treatment and transport of the critical flows; the adaptability to passive- and natural technologies; the seize of space; and the overall resiliency to failure, inaccurate use and sabotage. The paper focuses on rethinking the urban planning as a whole, with emphasis on a changing attitude towards the relationship between the technical infrastructures of especially the energy flow related networks and the 'suprastructure'. Basis forms the application of the power-law concept, also known as Pareto or Zipf to the technical infrastructures concerning the essential flows in the built environment. Not only the (known) dependency of decentralized concepts on central networks, but also the reverse will be argued: the needed aggregation of decentralized micro-networks, or clusters and systems to the complex and continuously growing centralized networks. Main objective is to cope with the risks of rising complexity and continuing unity, apart from the rising need of resilience of the overall network in case of loss of parts. This, for our economy is increasingly reliant upon interdependent and cyber-supported technical infrastructures and information systems.

1 INTRODUCTION

Most of the existing urban infrastructures can be typified as 'end-of-pipe' planning strategies. We transport waste, wastewater and even relatively clean rainwater outside urban districts to centralised treatment plants. We attempt to generate electricity or gas in centralised gas plants. The upshot of this is much more than the transport requirement and the use of extra material and energy. The inevitable mixing of different elements and/or qualities is detrimental to the overall quality. The majority of the transported flows undergo qualitative and quantitatvie losses during transport, which also has serious impacts on the immediate environment. The way to permanent urban development appears to be elusive. In modern town planning new inventions and the introduction of intelligent reduced (or light) infrastructures are required. In the long term only closed cycles for processes and use of material could result in a permanent urban environment.

Building infrastructure almost always implies slow and large-scale processes. For a structural solution and preservation, the technical infrastructure should be considered because it will be leading for the design and the allocation of the faster dynamics of the overlying layers: the layer of the overground "networks" and that of "occupation". The infrastructure strongly correlates with production (supply as well as drainage). A change desired in the infrastructure, e.g. a bottleneck with respect to capacity, can be solved by investing in extending the infrastructure (now often accepted), but often also by adapting the "production" or "treatment" in strategic spots of the (central) grid.

This is the background for the presented research (Timmeren, 2006). It tries to demonstrate the need to include interdisciplinary approaches to the essential flows (energy, water and waste) and belonging infrastructures, integration of strategies for raising public awareness and improved use of the different qualities of water and energy (cascading quailities, or so-called low-exergy design). It is argued that for a lasting sustainable urban development and a necessary improved network geometry (Watts & Strogatz, 1998; Banavar et al., 1999) with respect to these essential 'flows', further development based on the future path of scaling-up of different networks and users will have to be combined with decentralised sub networks, or clusters, aiming at autonomy.

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2 THE ESSENTIAL ROLE OF TECHNICAL INFRASTRUCTURES

2.1 *The relation infrastructure - suprastructure*

During the contemplation of the different flows and the several belonging energy- or water-concepts and belonging forms of technical infrastructure one needs to pose the question: what is the real exigency of this specific infrastructure and which is the best physical form of appearance? Additionally one should think about the relation between (technical) infrastructure and the social goals that are aimed at, doing this as much as possible independently from the existing ways of thinking and existing arrangements.

In case of the stated question, one has to reflect newly upon which social needs exist, and which (technical) infrastructures belong to these needs. There is a common consensus in society about the necessity of fundamental facilities for meeting the most fundamental needs in the own living environment (support, protection, affection, understanding, participation, relaxation, expression, identity, freedom). Support, or maintenance, includes the availability of energy and food, including clean drinking water, and the removal of waste (water).

The different standards of societal needs and goals, which form the basis of all physical networks of logistical chains, including the (technical) infrastructures, are defined as the 'suprastructure' (Ruis, 1996). It is no use trying to introduce sustainability measures that harm the previous stated fundamental need. Many relevant participants however do not seem to realise that other, more sustainable alternatives can be found by abandoning the specific characteristics of the traditional paradigms rather than following them. The dominant participants have an interest in using existing structures as efficiently (economical) as possible and in developing them further with as few risky investments as possible. Looked on from the aim of "sustainable development", the common path of expansion selected (centralisation) is not necessarily the optimum as perceived subjectively.

The 'Development Alternatives Centre' (CEPAUR) together with the 'Dag Hammarskjöld Foundation' were the first in formulating the suprastructure of a society. The developed theory is based on two suppositions: First of all, fundamental human needs are not unlimited but restricted in number, moreover can be classified. Secondly, fundamental needs of different cultures and historical periods are the same (Max-Neef, 1991). In the decision processes concerning changes or extensions of the technical infrastructure the decision-making will be optimal if the suprastructure (strongly related to planning) and the infrastructure (maintenance of the planned) are tuned in well to each other. This is easier said than done since there is a matter of a 'centralisation paradigm' in case of technical systems (concepts) and belonging infrastructures. This goes especially for the essential energy- and waste- and (waste)water flows.

It has turned out that the ongoing processes of liberalization have put pressure on the importance of the certainty of supply of energy, and also removal of waste and waste water. Working certainty of supply and independence out in further detail seems necessary, or even essential. A possibility is connecting or disconnecting (decentralised) sustainable sub production (generation or processing capacity). This may be realised by including sustainability, via reliability, as an added value at relatively little cost, e.g. in the form of a decentralised utility and backup, possibly even aiming at autonomy. Too little advantage is taken of this aspect of sustainability. It may involve short-term interventions for long-term guarantees (sustainability, guarantees for supply/processing and in the end affordability). Such a principle may be useful as a kind of fall-back scenario for, for example, a serious and unforeseen dysfunction of the current process of further scaling up and liberalization of sectors.

So essentially two future paths for the development of (sustainable) technologies and concepts concerning the energy and sanitation (water and waste) flows are distinguished: further development based on the future of scaling-up and heteronomy of different networks and users, and decentralisation with the aim of local autonomy (or even autarky). In short concepts based on the "economies of scale" versus concepts based on the "scale economy" (Timmeren, 2006).

With respect to both extremes, globalization (heteronomy by interconnection) and striving to complete (ecological) autarky cannot be seen as an optimal development for the so-called 'suprastructure', or, in other words, a good, democratic basis for societies. And what is more, neither of them (in their specific pure form) is to be considered a good basis for further, sustainable development of the structures for those societies. For the essential 'technical infrastructure' (i.e. energy, waste- and water infrastructure), the dynamics of non-simultaneous, slow transformation necessary for attuning the complex structures of society, the "flows" and nature (or natural processes) implies that it is wrong to still think in separate systems within integral development processes. That is, since there is an increasing interconnection and interdependence in the technical infrastructure of the essential flows. Although an increasing interdependence and heteronomy between people and their institutions can be noticed, Goudsblom (Vries and Goudsblom, 2002) claims that the dependence on natural forces has become less direct. The technical and social chains between the production of objects and their use ("source and service") are longer and more forked (complex).

In practice, we see far-reaching semi-autarkic projects being connected to central infrastructures. What still is unknown is that, to be able to connect to the electricity infrastructure, to a larger extent than approximately 30% of the network capacity, projects (subsystems) based on autonomy and/or renewable (discontinuous) sources new network philosophies (or network geometry) and use of these centralized grids should be introduced. Within the existing electricity network it is not possible to replace existing generation by generation through (variable) renewable sources for a larger extent than this 30%. For the sanitation infrastructures alternative use of existing networks offers possibilities to cope with increasing costs due to aging and shortages on capacity due to expansion(s) and introduction of higher densities (Timmeren, 2006).

2.2 *Increasing 'heterononomy'*

There are clear differences between the characteristics of the various central networks, in the energy and sanitation sub flows each as well as between the energy and sanitation supply as a whole. They are caused by different "central scales" of application and different extents of visibility, but also by the management structure and the presence or absence of liberalization processes. For sectors that are left to market forces, positive effects are to be expected on the efficient use of the infrastructures, and in Europe, by oligopolistic market types and on the affordability of the accompanying services. However, market participants have no interest in overcapacity, which puts pressure on the reliability of supply (by a maximum bid on the available capacity). Pressure can also be put on the other long-term interests, including maintenance of grids and investments in, research into or application of innovations, e.g. those that aim at sustainable development (Künneke et al., 2001). At the same time, main aspects for users are sustainability, a guarantee on supply and processing and affordability (Quist et al., 1999).

Where the essential infrastructures are concerned, the liberalization of the markets shows that the goals set concerning sustainability cannot always be accomplished in an integral way. At a national level, there is too little grip on the developments. The demand for supervision or rules at a supra-national level is being heard, and this causes one of the reasons for liberalization with respect to essential sevices to be surpassed. The "dialectics of progress" and the so-called "prisoner's dilemma" force themselves upon us: the deviation from this specific unsustainable (end-of-pipe) type of solution(s) is so expensive and will involve such far-reaching social consequences that there seems to be no other choice than continuing with these relatively expensive infrastructures and systems. Besides of that, the distance created between the (environmental) problem and its solution leads to more and more complexity. The process of changing the interrelated public and private services, systems and infrastructures is becoming more complicated and less predictable. Together with the increased scaling, the convergence of utilities and the growing number of parties and techniques involved have increased the end users' (consumers') subjective dependence, or heteronomy.

3 NEW PLANNING APPROACH AS A BASIS FOR SUSTAINABLE DEVELOPMENT

3.1 *Autonomy through interconnection and heteronomy or through decentralisation*

There are two development processes concerning use of technology for the purpose of autonomy with respect to the essential flows (energy & sanitation): viz. first, the efficiency and improvements in the integration of sub techniques and co-ordinated, connected concepts, and, second, a better harmony between supply (input) and demand of the (different) sub flows. Additionally, there are two more general underlying development processes. The first is the environment-technical, environmental and, to some degree, also social optimization of decentralized systems within semi-autonomous projects. The second underlying development process concerns the link to economic applications related to the surroundings, often determined by soil or users, including taking nutrients back to agriculture and other lateral applications or possibilities, mostly concerning 'services' such as car-sharing systems. In addition to the possibility of other types of use of (agricultural) grounds, the link to agriculture (i.e. 'urban agriculture') may not only lead to a structurally different infrastructure (aboveground and underground), but also to different country planning as a whole, when applied on a larger scale (Röling and Timmeren, 2005). Some authors claim that this also implies a different (economic) organization: dependent on the scale of application, which amounts to incorporating decentralized participatory democracy or types of federation and confederation on different scale levels (Timmeren, 2006).

This also offers points of departure for interrelating "red" and "green" functions in environmental planning. Here, the aspects of vicinity and comfort are leading. In this situation, the search for an optimum scale of autarky or autonomy of the various essential sub flows in the built-up environment gains higher importance. The critical upper and/or lower limit set by the technology solving one of the sub flows will actually become indicative of the integrated system, and, consequently, of the other sub flows. However, it would be too easy to summarize the need for further-reaching sustainability and sustainable development, with autarky as their ultimate goal, with a plea for nature and natural processes in the city. The new structures should be found in larger freedoms, to be accomplished by closing circles on different levels than the ones belonging to current paradigms, so that a maximum variety of solutions becomes (or stays) possible.

In spite of the potential of the underlying optimization principle of the "scale economy" claimed in much of the literature and projects, and in spite of its importance, which was also proven, it has only been applied to a small extent. Consequently, there still are not many "economies of scale" in this area. However, the sub aspects concerning the application freedom and environmental integration (smaller sizes, fewer secondary demands, etc.) and user-related demands (comfort, ease of use, costs, etc.) do improve noticeably. In projects with a clear organization (or organizational structure) and with responsibilities clearly agreed on the often foreseen 'problem' of larger complexity often occurring in integrated systems is not necessarily perceived as only a disadvantage. For users and participants, it emphasizes the additional or 'lateral' fundamental needs of "identity", "participation", "relaxation", "freedom" and "self-expression".

The critical limits that are set for parts of the integrated system, together with changing conditions regarding environment, use, technique or market, imply that such semi-autarkic systems should be considered unstable by definition. Because of the fundamental need of protection of maintenance, semi-autarkic projects should be able to meet such changes, either by means of a connection to a “backup” system (often on higher scale levels), or by means of parallel solutions (hence over dimensioning) within the system itself.

3.2 *Changed network philosophy*

In energy supply, there should be more emphasis on increasing the flexibility in the current (infra)structures, including Town and Country Planning in its entirety. The more so since it can be expected that there will not be only one decisive future technology to solve the coming problem(s) concerning security of supply and sustainable development. Especially with respect to energy this asks for a simplification of the processes, products (or rather: services) and parties involved. A larger concentration on integral provision of services, or, in other words, the supply and management of integral packages, offers possibilities. This seems to be reinforced by the (ongoing) liberalization processes. Another solution is having the level of application attune better to the lifestyle and direct surroundings of the users.

The desired changed philosophy described has far-reaching consequences for the way in which infrastructures are designed and integrated. It is important to realise that the stability or resilience of networks is directly related to the their complexity. It is not the components of the various structures that matter, but the way they are organized together as intelligent structures. It is important to learn from the organization structure and topology of other existing adaptive, complex structures. Recognizing the structures of each network is needed for combining their optimally ongoing development, possible decline and damage done to them, whether desired or not, with constant or increasing sustainability and certainty guarantees for user. Random networks with complex topologies often occur in nature, but also in culture. The complexity of many social, biological, communication and transport systems finds its basis in a network that is rather interrelated and that is defined by the system components and their mutual interactions.

The mathematician Alexander (1966) was one of the first to recognize the importance of the underlying structure as the basis for the possible notion of spatial planning and the accompanying physical and social networks. He distinguishes two scale-dependent opponent structures: the tree axiom and the semi-grid axiom. Later research (Watts & Strogatz, 1998) shows that even the smallest addition of random connections to a well-ordered network leads to advantages known from social networks (Granovetter, 1983; Granovetter, 1973), also known as the “small-world” principle (Milgram, 1967).

As opposed to the social networks, the so-called “in-between distance” is relatively large. Within large-scale, aristocratic “small-world” networks, it turns out that a limited number of nodes has considerably more connections than the other nodes. These nodes are called “hubs” and can be considered as the pivots of a cluster. Well-ordered networks often consist of clusters, as do social networks. The importance of clustering is that the loss of one element will not result in any dramatic fragmentation of the network in disconnected subsystems (Barabási et al., 1999; Banavar et al., 1999). The ‘power law’ implies that there is a fixed relationship between the total number of connections and the total number of nodes. This ‘power law’ is also known as “Pareto”, “Zipf” or the principle of “self-organization”, and may be considered as the main generic effect of the increasing networks or complex structures. Moreover, together with the principle of “self-repair” it is the main characteristic looked for in the possible application of “natural technology” for the facilities for the essential flows within sustainable urban development.

Two regimes can be distinguished in complex networks: an exponential regime, leading to homogeneous, egalitarian networks; and a “scale-free”, aristocratic network, characterized by a clear difference in the number of connections per node. The aristocratic network structure approaches Alexander’s semi-grid axiom, but has a structure more complicated and subtle, which make complex structures more easily to be included into the notion of the semi-grid. It turns out that the largest networks with known topological data in the aristocratic network structure show the same characteristics because of further-reaching interconnection (be it on world-scale or not): scale-free characteristics and a distribution of the transport connections according to the principle of the power law.

Almost all structures and networks designed or “ordered” may be put on a par with the tree axiom and have egalitarian characters. In addition to the urban development structures of most (newly) planned cities and city districts, the North American electricity grid is also a relevant example. The interdependence of communication networks that are relatively simply accessible and connected to or integrated into the essential infrastructures becomes larger and larger; they are almost always characterized by the aristocratic structure as described above. Because of the desired guarantees for operational safety and sustainability to users at lower scale levels, it is of importance to consider the effects of change (expansion, disturbance, breakdown) at higher scale levels. Research into the resilience or safety of simplified networks, particularly distribution networks, shows that the aristocratic and egalitarian networks are very different from each other. When an uncoordinated breakdown occurs, e.g. because of incorrect use or age, egalitarian structures fall apart rather quickly whereas aristocratic structures allow for more than half of the nodes to be removed for the remaining parts of the network to perform well as a whole. When intentional breakdown occurs, e.g. in case of sabotage, the aristocratic structures turn out to be more sensitive, but it is relatively simple to secure the critical nodes in this type of network (in advance) or to isolate them (afterwards) without influencing the performance of the remaining network. The recent (2006) collapse (blackout) of extensive parts of the electricity grid throughout entire Europe after a relative small accident in Germany subscribes the previous, as does the Asian fall-out of internet and other communication means after the December 2006 earthquake near Taiwan.

It can be argued that the best ultimate goal, when elaborating on the principles of the "economies of scale", is a complex, adaptive aristocratic structure of each of the networks, or perhaps of the whole that they form together (on regional, national or 'Euregional' and even global scale). It implies "scale invariance" and "self-organization", which are desirable aspects. A precondition is that the network grows continuously by new connections and (decentralized) clusters, and that new connections are connected to the network following the power law, with so-called "multi-connected" connections according to the principle of "preferential attachment". With respect to this, and in order to be able to understand the necessary process of clustering it is of importance to know the underlying "powers" of the principle of "preferential attachment", the principle of "the rich-get-richer". As to this principle, Bianconi & Barabási (2001) argue that the aspect of "fitness" plays a role in competitive networks, or as they state: the principle of "fitter-get-richer". The aspect of "competitiveness" implies competition within networks rather than market competition between networks. The aspect of "fitness" should be defined differently for the various networks. For the essential flows and their infrastructures within urban development this implies a combination of the extent to which generation, collection and transport are flexible, uniform, consistent and technically & spatially optimized. Supply guarantee together with sustainability is the key word, and this can be reached by tuning and adjustment of quality, optimizing rotation time and smart network design. If the connections between weak nodes are made stronger, by the simultaneous introduction of more "weak connections" between the important nodes in the system, the whole infrastructure can acquire more robustness and, eventually, more perseverance. This is when the necessary mutual connection between operability and sustainability is taken as a basis.

3.3 *Decentralised solutions as a basis for sustainability and innovation*

The application and fitting in of new decentralized techniques and/or alternative network structures, does not suffice for the accomplishment of "sustainable development". Too often there is tension between the mechanisms and the institutions that regulate motivation on behalf of individual or joint wishes. In following the conventional centralization paradigm, this type of "ritualism" stands in the way of a development into a society with more opportunities for changes according to the principle of "conformity" (Merton, 2000). It creates niches of "sustainable development" of all alternatives that do not comply with the centralization paradigm (Kemp et al., 1998). This occurs in the shape of concepts that can be placed under "rebellion" and even "separation". Examples are to be found in some of the Eco-villages, co-housing projects and Eco-districts, started by private – sometimes collective – initiatives and in some instances as individual projects. Although fargoing projects such as the Eco-villages are to be considered as the application typology of "conformity" according to Merton's definition, they are often placed under the application typology of "rebellion" or even "retreatism" by the dominant institutionalized authorities, looking at them from their own context on the basis of the current paradigm.

Opportunities for a widely supported need for innovation are neglected here, and so is the chance of more significant "sustainable development", for example through scale invariance.

When started as a niche, it can be taken as a method of allowing innovations to grow for the purpose of a more structural and large-scale use. The starting points of the restructuring processes from the industry, known as "Empowerment" and "Business Process Re-engineering", are of interest for the (large-scale) systems and networks connected to the essential flows that they may form the onset of research into scale invariance in the crucial infrastructures and their innovations. On the one hand a more market-oriented attitude should be taken as its starting point, on the other a more local or surroundings-oriented way of organizing. The background for this is the global transformation of economies from being focused on "mass production" to a focus on "tailor-made for the masses". Particularly inspired by liberalization processes, there is now almost only attention for the first aspect within the crucial flows and their infrastructures. The second aspect (surroundings-oriented attitude) implies a larger and a more structural change, and offers better opportunities for innovation and further-reaching sustainability (at several scale levels). It is the result of the increasing demand for user-specific, "on-site" solutions.

In current central infrastructures of energy as well as wastewater flows, the possibilities of an alternative network layout are not or not sufficiently taken into account. More and more connections are made between the various networks and sub networks in gas and electricity networks, but this occurs because of considerations of capacity and economic (business) perspectives, rather than on the basis of the principle of network geometry.

Consequently, there is a direct interest for large-scale central networks to have subsystems as a decentralized clusters included into the complex network. Because of the principle of self-organization, it also offers the possibility and the guarantees for being able to make local decisions with respect to, for example, further-reaching sustainability without abandoning the principle of scale size ("economies of scale"). Systems within decentralized planning concepts may lead to networks, complex or not, with a more strongly decentralized network structure with part of the networks performing relatively autonomously. These may support flexible planning concepts in town and country planning. Moreover, the issue of a more precise attribution of costs to specific customers or transactions (which becomes more and more important as complexity decreases with ongoing liberalization) may be solved or may easier be solved.

3.4 *Low Exergy design*

Another important approach related to a changed urban planning and related network philosophy is the cascading use of resources, where high-grade flows are used in high-grade processes and residual waste flows are used in lower-grade processes, thus making the most efficient use of the initial value of a resource. This so called low exergy approach taken here is inspired by natural ecosystems, where processes run on the available (usually low exergy) resource flows. This approach is thus in line with the Industrial Ecology thinking of taking nature as a role model. "Low exergy design" and ecological approaches can strengthen the systems, methods and tools used for organizing, operating and supervising the urban environment and will minimize the negative impacts of urban areas on ecological cycles at all levels, creating efficient urban systems and livable cities. A life-cycle approach is mandatory here in order to capture all relevant environmental effects to ensure an overall optimisation of resource use.

4 CONCLUSIONS

One could state that the infrastructure of the essential (or critical) flows, due to its 'path-dependent', long term character, importance of network geometry and the existence of a limited number of dominant actors per network or flow, is determinative to what degree a project - varying in scale from a (part of a) building to a city or region- will or can be sustainable. Especially the (waste)water infrastructure and the energy infrastructure can be characterised by transported flows which are not drawn up out of ongoing 'ecologisation' and dematerialisation but out of efficiency in central management and other economical factors. From the point of view of sustainability the technical infrastructure and with it urban development therefore seems to be insufficiently efficient.

Differentiation and urban flexibility (i.e. buildings and infrastructures) are pre-conditions for anticipating long-term uncertainties, due to actual liberalisation processes, rising complexities and even sabotage. Sustainable starting-points are suppressed more and more by these changes. However, at the same time especially the urban scale can start up the necessary process of transformation towards real sustainable development, for it takes the best of two worlds. At present however, technical infrastructures still are leading to urban development, often even to the suprastructure of society. There is rising concern for the complexity of structures, aging of existing (technical) infrastructures and even several places of congestion. The development can be qualified for being 'path-dependent': as for the essential flows this means a 'centralisation paradigm', resulting most of the times in solutions that still include mixing of different (sub) qualities (i.e. are not based on cascading- and exergy principles).
Within this process of path-dependent development, the existing infrastructures therefore can be considered as a growing restriction for sustainable interventions on lower scales, and therefore sustainable development. The strategically or even random integration of decentralised clusters (which preferably approach autonomy) in interconnected centralised networks will help to improve the resilience, flexibility, security and sustainability of the overall network. At present mostly only the dependence of decentralised systems on centralised systems -in general for reasons of storage and/or backup- have been put forward. However, the outcome of the underlying research shows that especially in case of ongoing interconnection, centralisation and liberalisation, both future paths for sustainable development, the 'economies of scale' and the 'scale economy' need one another mutually.

5 REFERENCES

Alexander, Ch. The City is Not a Tree 1965. Architectural Forum, nr.04 & 05 / Design, nr.02; translation in: SWB, Bergeijk, Belgium. 1966.

Banavar, J.R., Maritan, A., Rinaldo, A. 1999 Size and form in efficient transportation networks, Nature vol.399

Barabási, A.L., Albert, R., Jeong, H. 1999 Mean-field theory for scale-free random networks. online publ.: arXiv:cond-mat/990768 v1 , Elsevier Preprint.

Bianconi, G., Barabási, A.L. 2001. Competition and multiscaling in evolving networks. Europhysics Letters, vol.54,no.4.

Granovetter, M. 1973. The strength of weak ties. American Journal of Sociology nr.78.

Granovetter, M. 1983.The strength of weak ties: a network theory revisited, Journal Sociology Theory nr. 1.

Kemp, R., Schot, J., Hoogma, R., 1998. Regime Shifts to Sustainability Through Processes of Niche Formation. The Approach of Strategic Niche Management, Technology Analysis &Strategic management, Vol.10, No.2.

Künneke, R.W., Bouwmans, I., Kling, W.L., Poelje, H. van, Slootweg, J.G., Stout, H.D., Vries, L.J. de, Wolters, M., 2001. Innovatie in energienetwerken. Faculty of Policy and Management & Delft Interfacultary Research Centre (DIOC) 'Design and Management of Infrastructures', (TUD), Delft

Max-Neef, M.A. 1991. 'Human scale development. Conception, application and further reflections', New York

Merton, R. 1957. Social Theory and Social Structure, Glencoe, Free Press. in: Röling, N. (2000). Gateway to the global garden. Beta/Gamma Science for Dealing with Ecological Rationality, University of Guelph, Canada.

Milgram, S. 1967. The small world problem. International Journal Psychology today nr. 1.

Quist, J.N., Knot, J.M., Wel, M. van der, Vergragt, Ph.J., 1999. Strategies for Sustainable Households, Proceedings Symposium on Sustainable Household Consumption ', pp175-186, Groningen.

Röling, L.C. and Timmeren, A. van 2005. Introducing Urban Agriculture concept in Urban Planning: The Park of the 21^{st} Century. Proceedings Int. Conference Sustainable Building (SB05), Tokyo.

Ruis, M.J. 1996. Visies op Infrastructuur en duurzaamheid. Erasmus Studiecentrum voor milieukunde. Erasmus University. Rotterdam.

Timmeren, A. van, 2006. Autonomie & Heteronomie. Integratie en verduurzaming van essentiële stromen in de gebouwde omgeving. PhD thesis. Delft University of Technology. Eburon Academical Publishers, Delft (English edition 'Autonomy vs. Heteronomy' is due: Autumn 2007, IOS Publishers).

Vries, B. de and Goudsblom, J., 2002. Mappae Mundi. Humans and their Habitats in a Long-Term Socio-Ecological Perspective. Myths, Maps and Models', RIVM, Amsterdam University Press, Amsterdam.

Watts, D.J. & Strogatz, S.H., 1998. Collective dynamics of small world networks, Nature 393, 440-442.

The certification of buildings as an enterprise strategy of the real estate sector: a national scope analysis

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ABSTRACT: In an analysis made to the civil construction sector and to its role in the national energy consumption, we argue the way this sector could contribute for the CO_2 emissions at the same way it can contribute so that Portugal could fulfil the goals established by the Kyoto Protocol and stimulating other sectors of activity, witch have very restricted targets defined, to develop themselves. From the point of view of the sector of the construction in itself, the competitive advantages from the incorporation of sustainability principles are presented, especially in what it respects to the energy performance. The main conclusion of this paper is that the contribution of this sector can have advantages that we can define as having 4 dimensions: for the company in itself, for the consumer, for other sectors of activity and, consequently for the country development.

1 DEVELOPMENT AND SUSTAINABILITY

Nowadays the concept of sustainable development is relatively well known for the citizen, and for a set of regional and global actors and the politicians that make decisions, that look to integrate its principles in the local, regional and national strategies. Its definition was introduced in the world-wide scope in 1987, for the Brundtland Report as the development that allows to satisfy the needs of the present generations, without compromising the satisfaction of the needs from the future generations (Brundtland, 1987).

The wakening for this reality appeared with the perception that in result from the increasing of search of resources by the humanity and the form as the same ones was used was leading a decrease in the Planet biodiversity to a rhythm of about 50.000 species per year (Brown, 1991). On the other hand the scene of search and consumption of materials increased to a hallucinating rhythm due to an exponential growth of the population (in a society each time more developed and with standards of raised requirement each time bigger), for another hand the amount of available resources presented a completely inverse scene (Yeang, 2001).

The sustainable development is, nowadays and in contrast of what it happened in the beginning of its introduction in the world-wide sphere, a much more embracing concept that the mere environmental protection, implying concerns like the quality of life (and not only with the economic growth), the equity between the people and its access to the well-being levels (including the eradication of the extreme poverty) and the proliferation of chances between generations. One of the forms to enter the impact associated to the activities of each citizen of the Planet consists in determining its Ecological Footprint (from the English, *Ecological Footprint*). Ecological Footprint is calculated by adding some productive land parcels (land and sea) which are necessary to produce the resources used and to assimilate the residues produced for one unit of population - it compares the use of the natural resources with the capacity of the Nature to supply them, so Ecological Footprint is used as a sustainability indicator - or unsustainability, in the case to have ecological deficit.

1.1 *The National Strategy for Sustainable Development*

The National Strategy for Sustainable Development (ENDS, 2004) represents the commitment of the Portuguese government assumed internationally in the scope of the Lisbon Strategy, whose main objective is "to make Portugal, in the horizon of 2015, one of the most competitive countries of the European Union, in a picture of environmental quality and social responsibility and cohesion", implying, among others targets, a faster, but sustainable growth, of the Portuguese economy, less intensive in energy and natural resources consumptions and integrating the environmental protection in the country development model, while it considers natural heritage as a positive factor of differentiation.

In this strategy, the enterprise sector is seen as a mechanism of promotion the social and environmental responsibility, through the development of technologies, certification, voluntariness and continuous formation of its workers. However, the dialogue with groups of in*terest (stakeholders*), necessary to the conduction of a sustainable growth, is not strengthened in the strategy, as well as the necessity to promote this type of strategies next to the top management (Santos, 2004). The ENDS strengthens the sustainable responsibility of the industry and the private sector on the implementation, expansion and information of practical on its form to operate.

As global goals to be reached up to 2015, the ENDS2004 considers that Portugal seats in a economic development clearly next to the European average, to become one of the first 25 countries of the index of human development and one of the 15 more competitive countries of the world. To reach these goals, the following objectives must be reached: assure the reduction of gases with greenhouse effect (GEE) that Portugal has compromised (less 27% in period 2008-2012, from 1990 levels), reduce industrial impacts in natural resources in about 1/3, assure the treatment of residual effluents for 90% of the population and the supply of quality water for 95% of the national population, objectives that could clearly fit with the sector of the construction.

2 SUSTAINABILITY AND CONSTRUCTION SECTOR

The link between the sustainable development in its three dimensions, known as *triple bottom line* (economic, social and environment) and the construction industry is particularly important if we account the impacts of this sector, for instance in the contribution to national wealth – economic dimension, in the offer of a raised number of work ranks - social dimension or in the raised tax of natural resources consumed and environmental loads produced - environmental dimension. This link must be seen not only as a negative impact, but due to its importance in the three dimensions, as a chance of create a set of improvements, that it can be carry out, to the level of environmental impacts management from this sector and that, in its turn can originate many significant advantages for the Portuguese economy, as it will be gone to see of followed.

With the increasing migration of people for cities (currently 80% of the European population lives in cities) the pressure on an urban environment, sometimes already little healthful, was intensified since the industrial revolution. In 1992 in the Rio Conference, became evident the need to alert the main politicians and other actors in a general way to the importance of create a constructed environment healthful which could lead to the promotion of the quality of life of all the citizens.

2.1 *Construction Triple Bottom Line – practical implications*

In the recognition of the economic pillar we can conclude that the industry of the construction represents about 10%-12% of the European GDP – Gross Domestic Product and contributes for about 50% of the GFCF - Gross Fixed Capital Formation, that is the investment in capital assets as lands, buildings, machines among others, similar values to the registered ones for Portugal in recent years. To develop a sustainable management, the legislating entities and public authorities must assure that the companies can operate inside of a balanced and adjusted economic system and in a competitive environment - a prerequisite for the sustainable development is a healthful economic environment, in which the companies can develop its commercial activities and generate profits.

On other hand, in the recognition of the social pillar associated to the construction industry, it can be verified the existence of about 2,4 million companies of this sector of activity (EU22), of which 97% are classified as Small and Medium Enterprises (SMEs) with less than 20 workers, that makes this sector the biggest employer of the Europe and implies a widened social responsibility, mainly in the formation, health and security of these workers. Its esteemed that 14 million operators (EU22) add 7.2% of the total of the direct employment and when we account for indirect employment it can be justified that the construction sector in the Europe uses more than 30 million workers (about 12% of the total employment created in Portugal it is supported by the construction industry) (Eurostat, 2007).

Finally in the recognition of the environment pillar it is known that, at the world-wide level, about 50% of the used nature virgin materials are consumed by the construction industry and that this activity, in a general way explores the natural resources far beyond the sustainable levels. In the OECD countries, more than 40% of the produced energy is consumed throughout the lifecycle of the buildings, the built environment produces approximately one third of GGE total emissions and the resultant waste from construction and demolition activities constitute one of the biggest waste streams produced in Europe, in spite of most is already recycled (OCDE, 2003)

2.2 *Sustainable Construction*

In the planning of the cities it is essential to promote interventions that guarantee the sustainability of the urban environment, in economic, social and environmental ways. The local Governments have an extreme importance in the sustainability principles application, supporting a strategic thought that foments benefits of an innovative and integrated form, in the economy, the society and the environment, aiming the development of a prosperous world but inhabitable, more just, shared and clean and the efficient use of the resources. On the other hand, the construction enterprises also have an important word to say, but they need to develop and to extend its knowledge through the creation of chances for Research & Development in this area in order to enable Portugal, to develop a construction sector with creative and innovative ideas, that allow them to meet the expectations of all the *stakeholders*.

With the gradual recognition of the importance and environment responsibility of the construction sector appeared the concept of sustainable construction, as well as some guidance for its implementation, evaluation and recognition of the environmental characteristics of the construction, mainly in the urban buildings. The concept of sustainable construction was for the first time related in the First Conference on Sustainable Construction (Tampa, 1994), by Prof. Charles Kibert, as the "*the creation and responsible management of a healthy built environment based on resource efficient and ecological principles*".

According to this concept, the sustainable construction aims, in a general way to fulfill two main objectives: (1) minimize the negative impacts of the constructions on the environment and, simultaneously, (2) create and maintain healthful environmental conditions for the users of buildings or the surrounding populations to the developed projects.

The sustainable construction must look through all the life cycle of the building and consider that the resources of the construction are the materials, the ground, the energy and the water. Kibert established the five basic principles of the sustainable construction: (1) to reduce the consumption of resources; (2) to reuse the resources to the maximum; (3) to recycle materials of the end of life of the building and to use recycled resources; (4) to protect the natural systems and its function in all the activities and (5) to eliminate the toxic materials and by-products in all the phases of the life cycle.

Although we are able to deduce from here the two other dimensions of sustainability, its implications are, mainly, environmental. The reduction of resources consumption, as water and energy, or the reutilization and recycling of materials brings, to whom who apply these principles, a reduction of the costs associated to the traditional practices. On the other hand, the delivery of a service to the customer who allows him during the use of the building to have fewer costs is an advantage to the reputation and competitiveness of the enterprise who develops a building with these practices.

Another definition of sustainable construction, more recently presented for United Nations defines it as "a holistic process, looking for recover and keep harmony between natural and built environment and to create habitability conditions that affirm the human dignity and encourage the social and economic equity". At the European level, the 6^{th} Environment Action Programme is well clearly about the necessity of implement sustainability this sector of activity which leads to the definition of the Thematic Strategy on the Urban Environment with four specific areas of act: urban design, urban management, sustainable construction and transports.

2.3 *Energy as pillar of the Sustainable Construction - the energy performance of the buildings*

The sustainable construction is one of the priorities declared for the future of the construction sector (European Commission, 2007). One of the main points associated to sustainable construction must emerge through the improvement of the energy performance in the buildings. This performance must recognize in first place the amount of energy used to construct the building, and looking for to minimize it through good practices, as well as considering the type of energy used looking, whenever possible, renewable sources.

To improve the energy performance of the buildings allows to reach a vaster set of objectives, such as: (1) reduction of the global needs of energy production, (2) reduction of the emissions of carbon dioxide, and consequently of GGE, (3) improvement of comfort in households and workplaces, (4) contribute for cleaner cities, (5) improvement of urban regeneration, (6) improvement of the health of the population and promotion the social inclusion and (7) increase the standards of living of the European citizens. To improve the energy efficiency in buildings is one of the few areas of the public politics where there are only "winners", however, none of these "winners" can be to certain to emerge, by purely trusting in the existing forces of market. The barriers that exist currently are too much great, so only just one fast program to improve the sustainable construction in the buildings can obtain this target.

Buildings are the main users of final energy in the European Union, responsible for about 40-45% of the energy use in each State-Member. From consumption, the residential sector is responsible for two thirds and the commercial sector (tertiary or of services) for one third of the use of the energy in the buildings. In the households, 70% of the use of energy is estimated to heating and refrigerating air and water, and in the sector of services this value rounds 50%. In Portugal the final consumption of energy associated to the set of the sectors of civil construction and public works, households and services is of the order of 34% (DGGE, 2005).

Table 1. Energy consumption from Residential and Offices (INETI)

	Residential Sector	Office Sector
Final Energy consumption	13,1%	16,5%
Energy Profile	Low consumption by household (~ kWh/yr) vs. Many households	Big consumption by office (~ MWh/yr) vs. Few buildings
Equipment and Illumination	25%	10-30%
Heating and Cooling	25%	30-60%
Kitchen and Sanitary Hot Water	50%	10-20%
General	Almost 30% of final energy consumption About 62% of final electricity consumption	

The consumption levels for square meter occupied are to increasing. In the residential sector, between 1985 and 1997, the average size of an European habitation increased from $83m^2$ to 87 m^2, what leads to an increase in the consumption. In the sector of services, the consumption for square meter increased more quickly than the total of square meters occupied, growing about 1.3% per year during the decade of 90.

Currently it is accepted that at least one fifth of the energy that today is used could easily be eliminated, preserving about 340 million tons of carbon dioxide per year. Some estimates of the industrial sector go far, identifying that about 430/450 million tons could be conserved up to 2010 (in contrast of what it happens in other sectors). This represents about 12% of the actual emissions, two thirds of the commitment of Kyoto and the equivalent to 215 million tons of oil equivalent (Mtoe).

In Portugal, the reduction of the CO_2 emissions is a strategic objective of the Central Govern, who looks to define strategies in this direction, as the National Plan for Climate Changes (PNAC), the program 3E - Energy Efficiency in Buildings, the E4 program - Energy Efficiency and Endogenous Energies, and others. From 2003 these strategies had become more important with the revision of legal regulation to optimize the energy performance in buildings, such as the RCCTE - Regulation of the Characteristics of Thermal Behavior of Buildings and the RSECE - Regulation of the Energy Systems and Climatization of Buildings, that had assumed more rigorous and ambitious criteria and, for another hand, the formation of energy technician for audit, capable to assure the fulfilment of the legislation.

3 SUPPORTED STRATEGIES OF SHARE = ADVANTAGES FOR ALL ACTORS

The successfully implementation of the measures foreseen for the regulations related in the previous point and other legislation on the theme of the consumption and the energy efficiency in buildings will have to be supported by a mild set of options taken soon since the phase of planning and conception of the building. It is important to win the barriers that still many architects and projectors face and evidence that the sustainable construction is not by itself, neither is associated, an architectural style, seating exclusively in the performance of the buildings through the implementation of the best adapted existing technologies to the climatic, cultural and market context where the building is developed.

To improve the energy performance of buildings it is possible to detach the resource to passive solar measures, passive measures, special passive solar measures or active solar measures, according with the presented followed.

Table 2. Examples of Solar Measures (TIRONE, 2004)

Passive Solar Measures	Choose excellent solar orientation Absence of shades pro-jected in the South façades Adjusted direct solar profits Double glasses Thermal continue isolation optimized in the exterior Specification of thermal inertia Prevent thermal bridges Promotion of natural ventilation
Solar Measures	Optimization of the natural ventilation, for example for hybrid ventilation systems, landscaped coverings (green-roofs), choice of materials in accordance with specific thermal characteristics
Special Passive Solar Measures	Walls of Trombe - gratuitous radiators (they have the capacity to accumulate heat of the solar rays during the days of winter and clean sky and at night to transmit these rays for the interior of the houses)
Active Solar Measures	Thermal Solar panels (heating domestic hot water with support of central boiler by gas) Integrated photovoltaic systems (production of electricity with linkage to the net)

The implementation of these measures soon, since the initial phase of project development implies the attainment of benefits during the following phases that go since the reduction of consumptions during the operation to the satisfaction of the final customer. They demand, however an anticipated and adjusted dialogue among different players of the construction sector, that have to be individual and collective boarded, so that the practices that today they are faced as out of common (not traditional) could become, in a very next future, practices common as usual.

Among different stakeholders that can implement the changes, it can be distinguished the governmental organizations (European Institutions, local states members, autarchies), enterprises and associations from the sector (concessionaires, promoters, constructors, contractors, manufacturers of construction materials), architects/projectors and engineers (Project Teams), insuring and financial institutions and finally, the consumer.

As responsible for the urban planning and the urban management, the governmental organizations (local, national or international) must assume their responsibility in the commitment with the Kyoto Protocol, since the local scale creating targets of performance for the reduction of the levels of CO_2 emissions for the atmosphere, in buildings, as well as introducing incentives to the sustainable construction, in the urban planning instruments like environmental performance indicators or define the license process, as for instance: reduce the period of approval for buildings with a good environmental performance, reduce municipal taxes for buildings with reduced impact on local infrastructures or increase the index of construction in function to the reduction of environmental impact. It is important to relate that the main examples of sustainable construction must be the public buildings.

On the other hand for the projectors, architects and other project team members of sustainable buildings it is urgent the need of create a wide range database with tools for the practice of sustainable construction, as well as the creation of a universal method for the evaluation of the performance of the buildings, adapted to each climatic and cultural context. The capacity of project teams in joint route into a common objective (including architects, people from real estate promotion, manufacturers, constructors, environmentalists, civil and mechanical engineers, etc.) it is an area that needs a radical change, seeming to still exist many times ellipses of the part of these intervening ones in opening its horizons for new (and sometimes simpler) solutions. A good incentive to this change would be, for example, the creation of architecture awards that considerer environmental dimension.

The real estate and construction promoters, while building producers that we want to could be sustainable, must start including sustainability requirements and optimize energy performance of its buildings wants either to its proper team members or their contractors. The national public administration recently gave the first steps for the creation of a supported structure of ecological public purchases, through the Resolution of the Cabinet n.º 65/2007, of 7 of May that foresees a national strategy of inclusion of sustainability requirements in the incumbencies of public acquisitions, for the period of 2008-2010. Although this strategy shows already one strong politics for incorporation of sustainability in diverse areas, there are still some doubts concerning its effective implementation.

4 CONCLUSIONS

The concept of the sustainable construction seats in the performance of the buildings and the implementation of the best available technologies adapted to the climatic, cultural and market local context is not associated with any architectural style and it reaches results of excellent performance. Many examples of good practices already exist by all the Europe.

This study will dedicate itself, essentially, to the analysis of the energy component that is part of the national built environment. The buildings must be conceived in order to assure an efficient management of the energy consumption. The used energy, especially the electric energy results mainly of the fossil fuel combustion as the oil and the coal and its productive process presents high environmental impacts due to the great amounts of gases with greenhouse effect, like CO_2 emitted. Besides this it implies the consumption of an limited and non-renewable natural resources, therefore the energy consumption must be faced as the main chance of improvement of buildings performance.

In Portugal, the electric energy have its bigger origin in sources not renewable and represents an important parcel in level of importation, leading us to a country extremely dependent (in energy perspective), contributing negatively for the trade balance of the country. Thus, associated to environmental impact of the consumption of this resource results in economic problems with the increasing price of the oil barrel, like its amount goes diminishing.

These trends of growth are compromising the fulfillment of the Kyoto Protocol targets which Portugal was signatory. In accordance with the last studies (PNALE), Portugal decided to acquire rights of CO_2 emissions equivalents to 348 million euros, for the period between 2007 and 2012, in case of not modify the actual development politics. This value is equivalent to a right of emission of 5,80 Mt CO_{2e}/yr of which about 3,70 Mt CO_{2e}/yr correspond to national deficit (having in account the politics and measures added at PNAC) and 2,10 Mt CO_{2e}/yr will be acquired as national reserve (PNAC and PNALE).

Acting at reduction of consumption energy levels in construction sector and throughout life cycle buildings will allow, not only contribute for preservation of environmental resources, but also increase of quality of national buildings, reduction the expenses with energy in families expenditure, improvement of level of performance of real estate promotion and construction companies that will apply these measures (with advantages of reputation and competitiveness among the sector), to contribute to the fulfillment of the Kyoto Protocol and, consequently, for the "quality" of national accounts relative to the trade balance and balance of payments. With reducing, and if possible elimination, the need to Portugal acquire rights of CO_2 emissions, the construction sector will contribute for the increase of the national wealth (through the increase of the GDP, for reduction of energy imports needs) and the development of other sectors of activity where the act edge is more reduced.

The urgency of a strategy adjusted to the construction sector imposes for the fact of this is a sector of activity that was stagnant during many years. On the other hand, the edge of improvement in this sector is evident in different stages of the life cycle of one building.

One of the interactions of this sector with the activity of other sectors (especially those enclosed for the PNALE and submitted to the reduction of its emissions) is concerned with the fact that the reduction of the national emissions it is possible to obtain with improvements at the buildings level (during construction, operation and demolition/renewal) which allows the development of activities on other sectors like the paper. This sector is one of the most important national liquid exporters and contributes positively for the national scale of payments, however, even so since 1990 have start to invest in new technologies that allow the reduction of the emissions, has reached a stage where even that technologies do not improve significantly the performance to this level (of emissions), for what they will only be able to fulfil the reduction established at PNAC, linked from the Kyoto Protocol if they interrupt its activity of production, what would bring serious consequences for the national economic structure.

Thus, it is obvious the benefits that the improvements at the level of the energy performance of the construction sector can bring for the sector, the consumer, but also for other sectors of activity and to our own country.

REFERÊNCIAS

ALMEIDA, Manuela; BRAGANÇA, Luís – *Curso Prático de Térmica e Acústica de Edifícios*, Fevereiro 2007, Lisboa

BRAGANÇA, Luís; MATEUS, Ricardo – *Tecnologias Construtivas para a Sustentabilidade da Construção*, 2006 Edições Ecopy Porto

BROWN, Lester; FLAVIN, Cristopher; POSTEL, Sandra (1991) – *Saving the Planet*, W.W. Norton, New York

BRUNDTLAND COMISSION, 1987, *Our Common Future (The Brundtland Report)*, World Council on Sustainable Development (WCSD), Oxford: OU

Despacho Conjunto Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional e Ministério da Economia e Inovação, de 28 de Setembro de 2006, que aprova o PNALE II – Plano Nacional de Atribuição de Licenças de Emissão 2008-2012

Diário da República (2006), DR 162 Série I-A de 23 de Agosto, Presidência do Conselho de Ministros, Resolução n.º 104/2006 que aprova o PNAC 2006 - Plano Nacional para as Alterações Climáticas 2006

Diário da República (2006), DR 67 Série I-A de 4 de Abril de 2006, Decreto-Lei n.º 79/2006 do Ministério das Obras Públicas, Transportes e Comunicações que aprova o Regulamento dos Sistemas Energéticos de Climatização de Edifícios (RSECE);

Diário da República (2006), DR 67 Série I-A de 4 de Abril de 2006, Decreto-Lei n.º 80/2006 do Ministério das Obras Públicas, Transportes e Comunicações que aprova o Regulamento das Características de Comportamento Térmico dos Edifícios (RCCTE);

Directiva 2002/91/CE do Parlamento Europeu e do Conselho, de 16 de Dezembro de 2002, relativa ao desempenho energético dos edifícios, publicada no Jornal Oficial das Comunidades Europeias de 04/01/2003

ENDS 2004 - *Estratégia Nacional para o Desenvolvimento Sustentáve*l – acedida em Maio de 2007 em http://www.estrategiadelisboa.pt

INETI – Instituto Nacional de Engenharia, Tecnologia e Inovação, acedido em Maio de 2007 em (http://www.ineti.pt/)

OCDE – Organização para a Cooperação e Desenvolvimento Económico, 2003 – *Environmental sustainable building – challenges and policies*, OCDE, 194 pp. Paris, França

TIRONE, Lívia – *Uma Arquitectura Sustentável para a Europa*, Primeiro Congresso sobre Construção Sustentável, 2004 - Leça da Palmeira

SANTOS, S., 2004, *Role of Business in Sustainable Development and Poverty alleviation – The Portuguese example,* paper submetido a concurso do World Bank Institute e Zicklin Center for Business Ethics Research

YEANG, Ken (2001), *El Rascacielos Ecologico,* Editorial Gustavo Gili, Barcelona

The sustainability in rehabilitation and in its education

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ABSTRACT: Rehabilitation design is not an activity restrictedly practiced in Architectural offices, but also taught and practiced at Architecture schools. Architects and students have to define their own method to approach rehabilitation design developments; however, they can be theoretically supported. The doctoral research RE-ARCHITECTURE theorized a rehabilitation design process; which was tested by Architecture students in the Netherlands and Portugal, during the academic year of 2005/2006. To better control the effective degree of the contribution, students filled in two questionnaires, one before and one after the development of a rehabilitation design, sustained by RE-ARCHITECTURE. These results sustained the improvements and developments of the simultaneously developed design process support system, RE-ARCHITECTURE®. This paper presents a survey of the results of the Portuguese students.

1 INTRODUCTION

Rehabilitation design is not an activity restrictedly practiced in Architectural offices, but also taught and practiced at Architecture schools. It is certain that each architect and student must define his own method for rehabilitation design developments. However, this process should not be detached of theoretical-practical support, such as the one available at RE-ARCHITECTURE, neither at the Architecture schools, nor in the offices.

Facing the serious levels of lifespan unconsciousness among rehabilitation design developments, the doctoral research *RE-ARCHITECTURE lifespan rehabilitation of built heritage;* undertaken by the Architect Ana Pereira Roders, guest PhD researcher at the Eindhoven University of Technology; theorised and implemented a rehabilitation design process (see Figure 1), which takes forward lifespan consciousness and the required respect for the past, the present and the future of any building.

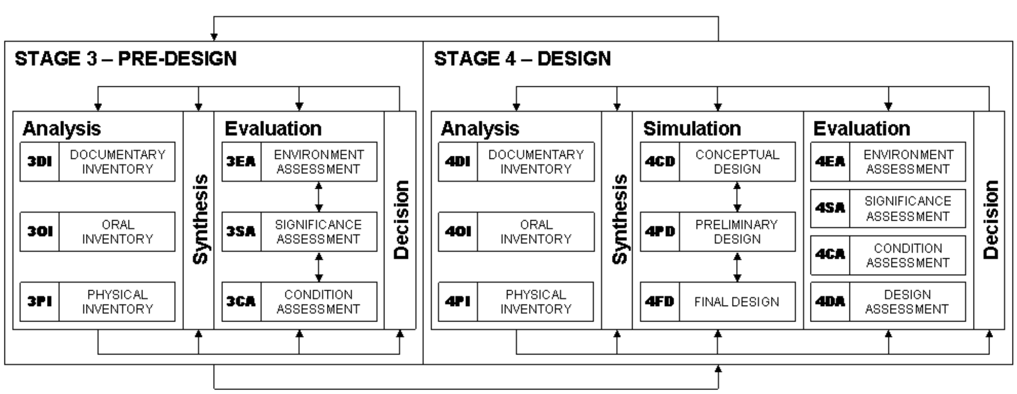

Figure 1. The lifespan rehabilitation design process (Pereira Roders, A. 2006)

In order to verify the applicability of the theorised design process a test was planned, involving architecture students, from the academic year of 2005 / 2006. For the effect, two European universities were chosen, the Eindhoven University of Technology (The Netherlands) and the Superior Institute Manuel Teixeira Gomes (Portugal). The following chapters describe the test results of the Portuguese students.

2 METHOD

The Portuguese students were invited to develop a rehabilitation design of an obsolete building, a water tower, in the city of Vila Real de St. António. The design was developed during three months and supervised by the architects Ana Pereira Roders and Isabel Valverde. To be able to control the students' evolution, the test period started with a pre-survey (questionnaireA2). The test was concluded with the accomplishment of a post-survey (questionnaire A3). Questionnaire A2 was filled in by 19 students. It intended to identify the students' previous participation in rehabilitation designs, their interest for rehabilitation, concepts and methodologies used by the students to develop, designs before getting acquired with the main principles design process theorized in RE-ARCHITECTURE.

Inversely, questionnaire A3 intended to verify the evolution of the students' knowledge, their level of self-critics and their lifespan / ecological consciousness. It was filled in by only 18 students, as one student stopped attending the course, after filling in Questionnaire A2. The test period allowed Pereira Roders to improve and complement the design process theorized in RE-ARCHITECTURE.

3 RESULTS: QUESTIONNAIRE A2 – PRE-SURVEY

3.1 *Previous participation in rehabilitation designs (A2.1)*

Six students (32%) among the nineteen affirm to have developed rehabilitations. The mentioned rehabilitations were those of rural houses and their environment developed during educational exercises, in previous years. One student presented a rehabilitation design of an abandoned urban area and a school for children; another student presented the rehabilitation of a commercial establishment. The students' strategies for these rehabilitations were mostly concentrated on the improvement of the conditions of habitability; but there are also references to prevent materials, construction components and the building environment from degradation.

The students who answered negative to this question passed directly to question A2.6. So, their answers have not been surveyed in the following questions.

3.2 *Interest for rehabilitation design (A2.2)*

The six students who participated in previous rehabilitation designs were unanimous in their interest for rehabilitation. The reasons that justify their interest are presented in Table 1.

Table 1. Reasons of interest for the rehabilitation design

reasons	students	%
introduction of better functional and comfort conditions	5	83
relation pre-existence and new existence	3	50
challenge raised by the difficulties of the building	1	17

"To endow the building with new functions and adjust them to the current needs" was considered a determinative factor for their rehabilitation designs by five students (83%). Three students (50%) considered "the relation between pre-existence and new existence" interesting and only one student (17%) referenced as challenge: "the difficulties met, converting an old into a rehabilitated building".

3.3 *Design process followed in previous rehabilitations designs (A2.3)*

The six students stated to have followed their own design process, together with the teacher's orientation. Table 2 presents the followed stages and activities, in their previous approaches.

Table 2: stages of work in the previous rehabilitation designs

stages of work	students	%
inventory (photos; sketches; etc)	5	83
analysis (building and environment)	4	67
preliminary design	6	100
final design	6	100
execution design	2	33
presentation	3	50

3.4 *Interest in following a different design process (A2.4)*

Two students (33%), among the six who developed rehabilitation designs before, admitted that they would not follow a different design process, as the one used was already appropriate to reach the objectives. The other four students (66%) demonstrated a bigger openness to use new design process. From the two students, who considered their design process as enough, only one justified his opinion with a short consideration: "(...) this is the process which I consider correct".

3.5 *Importance of the rehabilitation (A2.6)*

Seventeen students (89%) considered important to rehabilitate and only two students (11%) did not. Table 3 describes the reasons presented by the students to justify their considerations.

Table 3: reasons to rehabilitate

	reasons	students	%
building	prevention from degradation	2	10
	saving money (cheaper than new construction)	2	10
	preservation of the values / architectural characteristics	3	16
	preservation of the memory	9	47
	attribution of new functions	4	22
environment	development of urban planning	2	10
	preservation of the historical centres	2	10
	saving energy resources	1	5

Nine students (47%) pointed out "the preservation of the building memory" as the reason to rehabilitate. Next, three students (16%) mentioned the "preservation of the values / architectural characteristics" of the building and the "attribution of new functions" to the building. However, students demonstrated sensibility for more environment fields in which rehabilitation has an important role. Two students (10%) pointed out the "preservation of several urban zones" (historical centres), as well as, other two students (10%) mentioned the "development of urban planning". One student (5%) referenced "saving energy resources", as a reason to rehabilitate.

The two students who did not consider rehabilitation important, presented interesting and debatable arguments. One argued that each building has its own lifespan and that such period should be respected without any kind of "cosmetic" intervention. The other argued that due the fact that many buildings suffered from transformations in different periods, they should not be rehabilitated because they already lost their essence.

4 RESULTS: QUESTIONNAIRE A3 – POST-SURVEY

4.1 *Interest for their rehabilitation designs (A3.2)*

All eighteen students classified their design as interesting. Table 4 presents the reasons presented by the students to justify their interests in this design.

The curiosity to work with the RE-ARCHITECTURE design process was the most mentioned argument to sustain the interest in this design, referenced by six students (33%). Five students (28%) mentioned the challenge of not creating waste and also five named the challenge to work with the current conditions of the building. Four students (22%) mentioned, as factors of interest, to give new functions to the building and the ecological strategy.

Table 4. Reasons for interest on the design

	reasons	students	%
design process	curiosity to try the RE-ARCHITECTURE design process	6	33
building	challenge to work with the difficulties	5	28
	attribution of new functions	4	22
	recovery of the connection between building and city	2	11
	form and volume	1	6
	respect for the memory	1	6
environment	ecological strategy	4	22
	challenge of not creating waste (waste zero)	5	28

Table 5 presents the advantages pointed out by the students in their designs, filtered in three groups: the advantages regarding the design process, the building and the ones regarding the environment. Nine students (50%) mentioned the new functions and the accessibilities of the building; five students (28%) mentioned the preservation of the values and memory of the building, as well as other five students pointed out the restoration of the relation between building and community as an important advantage in their design proposals. The advantages regarding the environment were generally pointed out by five students (28%). Three students (17%) mentioned the introduction of reversible structures as an advantage in their designs; one student (6%) pointed out the planning of the final destination of the demolitions, as well as another student (6%) mentioned the use of recycled materials.

Table 5. Advantages of the design

	advantages	students	%
building	preservation of the values and memory	5	28
	approach between building and community	5	28
	attribution of new functions / accessibilities	9	50
	creation of a new image (reference)	3	17
environment	planning the final destination of the demolitions	1	6
	introduction of reversible structures	3	17
	use of recycled materials	1	6

The factors of influence during the process are presented in Table 6 and are again divided into two groups: the building and the environment

Five students (28%) pointed the preservation of the original image of the building, while other four students (22%) pointed the new functions attribution, through the introduction of a updated function program and accessibilities. In what regards the factors of influence on their rehabilitation design developments, sustainability was the most mentioned factor.

In agreement with the established strategy by the European Commission, sustainability involves three fields: task group 1 – (EFCM) environmentally friendly construction materials; task group 2 – (EEB) energy efficiency in buildings; task group 3 – (C&DW) construction and demolition waste management (EC, 1999). When the students listed their influential factors, sustainability was mentioned generically by five (28%) of them. However, when filtered according to the European Commission task groups, seven students (39%) mentioned the aim to recycle materials and three students (17%) mentioned the aim to use of alternative energies.

Table 6. Factors of influence on the design

	factors of influence	students	%
building	space qualities	2	11
	new functions / accessibilities / habitability conditions	4	22
	preservation of the original image	5	28
	preservation of the original structure	3	17
environment	sustainability (without specification of the field)	5	28
	recycle subtracted materials (sustainability)	7	39
	alternative energies (sustainability)	3	17
	reversibility of the new structures	2	11

4.2 *Support of the RE-ARCHITECTURE design process (A3.4)*

All students answered that the RE-ARCHITECTURE design process helped in the development of their designs and consequent improvement of its quality. Plus, they mentioned that RE-ARCHITECTURE also helped them to raise the lifespan consciousness while taking decisions in their designs.

Table 7 presents the areas where the design process was considered useful by the students. First, eight students (44%) considered the theorised design process important to create a base that allowed to sustain all design decisions more conscientiously. Second, five students (28%) mentioned that the methodology helped to organize the work, due to the fact that it divides the activities in stages and guides the development of each stage. Third, four students (22%) mentioned the alert given by this design process for questions less considered in current rehabilitation processes, e.g. ecological questions.

Table 7. RE-ARCHITECTURE design process – areas of support

areas	students	%
approach to questions less explored in rehabilitation	4	22
more conscientious approach of the taken decisions during the design process	8	44
understanding and distinction of the values of the building	1	6
systematization / division of the work in stages	5	28
demonstration of the rehabilitation importance	2	11
alert given to the ecological questions	2	11

4.3 *Use of different design processes (A3.5)*

Four students (22%) admitted the use of another design process if enabled; however, thirteen students (72%) stated to not use a different design process even if enabled. One student (6%) did not answer.

Table 8 presents the work stages in which the students liked to spend more time during the rehabilitation design process. Three students (17%) stated that they would have liked to develop further the analysis stage and two students the synthesis stage. Other two students mentioned that they would have liked to work equally (in time) in all stages, because all of them were balanced and important. So basically, it is mostly time management improvements.

Table 8. Stages of work

stages	students	%
analysis	2	11
synthesis	2	11
design	3	17
all the stages	2	11

4.4 *The importance of rehabilitation interventions (A3.7)*

While seventeen students (94%) answered that it is important to rehabilitate; one student, who did not consider important to rehabilitate already at the pre-survey (A2), maintained the same opinion in the post survey (A3). The second one, who had not previously considered, important changed his opinion in the post-survey (A3).

Table 9 presents a list of arguments, pointed out by the students, for the rehabilitation interventions. While eight students (44%) considered rehabilitation an important factor to develop the city; four students (22%) considered it important to rehabilitate, because it promotes the building rehabilitation through the introduction of new functions. The topics of preservation of the building's values, memory, identity; as well as, recycling of space, resources, energy, etc. were each mentioned by three students (17%). In this question, there were four students (22%) that did not give answers related to the question, so they were not considered valid for this survey. The student that considered rehabilitation not important was one of them.

Table 9. Reasons of the rehabilitation importance

reasons (more answers possible for each student)	students	%
development of the city	8	44
preservation of the values / memory / identity of the building	3	17
revitalization of the building giving it new functions	4	22
recycling of space / resources / energies	3	17
not valid	4	22

The buildings which the students considered apt to rehabilitate and to demolish are presented in Table 10. Five students (28%) considered that buildings which should be rehabilitated are the ones whose values are recognized, however, they did not specify what category and which values. Four students (22%) considered that all buildings should be rehabilitated; two students (11%) pointed the rehabilitation of buildings with historical values; also two students (11%) considered that rehabilitation should be carried out if the building has physical conditions that allow it.

At last, one student (6%) said that to decide for a rehabilitation or a demolition, one should analyse the building first. Three students did not answer this question. About the buildings to demolish, four students (22%) mentioned the buildings which values are not recognized; two students (11%) named the buildings which do not have physical condition that allows a rehabilitation intervention; two students (11%) pointed to demolish the buildings which rehabilitation is more expensive than new construction. One student (6%) considered the demolition for all the buildings without a relation with the city and 9 students did not give a reason for demolishing.

Table 10. Buildings to rehabilitate / to demolish

to rehabilitate	students	%
buildings with recognized values	5	28
buildings with historical values	2	11
buildings with aesthetical values	1	6
buildings with physical conditions that allow rehabilitation	2	11
previous analysis of the building to decide rehabilitation or demolition	1	6
all buildings	4	22
to demolish		
buildings without recognized values	4	22
buildings without relation with the city	1	6
buildings without physical conditions that allow the rehabilitation	2	11
buildings which rehabilitation is more expensive than a new construction	2	11

4.5 *Success of their designs (A3.9)*

About the results of the designs, it can be stated that thirteen students (72%) considered their designs as a success; four students (22%) considered the design as a failure. One student (6%) did not answer this question. The student's justifications for such success or failure of the design proposals are summarized in Table 11. Six students (33%) attributed as main reason for the success of their proposals the introduction of a new function and program in the building; four students (22%) considered that respect for the values and the identity of the building were the determinative factors for its success; and two students (11%) mentioned the respect for the original structure. The students who considered their proposals a failure, pointed as reason the fact that they did not have time enough to develop the design with the deserved quality. For example, they could not sustain their design solutions with technical drawings and studies, showing their effective level of sustainability.

Table 11. Reasons for the success / failure of the design

reasons for the success	students	%
respect for the values / identity of the building	4	22
attribution of a new function to the building	6	33
habitability conditions (comfort)	1	6
use of cheap materials	1	6
respect for the original structure	2	11
recovery of the relation between building and community	1	6
recycling of materials	1	6
environmental / ecological concerns	1	6
creative forms	1	6
reasons for the failure		
incomplete proposal	2	11
lack of time for technical solutions and studies about sustainability	2	11

4.6 *Ecological consciousness: the destiny of the subtractions (A3.11)*

Seventeen students (94%) planned what to do with the subtracted materials in the design developments. Only one student (6%) did not answer this question. The question considered four hypotheses regarding what to do with the demolitions. Five students (28%) planned to reuse them in the renewed building; five students (28%) planned to reuse them on the building site and seven students (39%) planned to recycle and reuse in the renewed building. No student considered the hypotheses of only recycle and have the material used in a secondary building, not related to this rehabilitation.

Table 12 presents the planned solutions for the subtractions and its applications. In the answers of the students, not many explicit examples of what they planned for the subtractions were identified. By verifying the generality of the answers, with reusing the subtracted materials concrete recycling was meant.

Table 12. Destiny of the subtractions / use / applications

destiny	students	%	use / applications		%
concrete recycling	11	61	technical floor (new floor)	1	6
			prefabricated panels	1	6
			mortar	2	11
			floors corrections	4	22
			new structures for accesses	2	11
			no examples	1	6
cut parts of the structure	3	17	cover of the reservoir used to create a lake	1	6
			new stairs	1	6
			pedestrian ways in the surroundings	1	6

5 CONCLUSION

The previously presented results show that for the students, rehabilitation was already at the Pre-Survey an intervention associated to preservation (physical and the memory of the building), adaptation (new functions corresponding to the current needs), urban planning and saving of economical and resources savings (A2.6).

In the Post-Survey, students maintained the same arguments regarding rehabilitation interventions. They related them with preservation, adaptation and management. However, this time they also considered important to contribute through rehabilitation to the level of urban development and sustainability (A3.7). Still regarding rehabilitation principles, RE-ARCHITECTURE theory explained that all buildings, independent from their classification, have potential to be rehabilitated; and should not be demolished without a proper technical assessment, considering the significance and condition of both building and its environment.

Regarding the buildings, which students considered apt to rehabilitate or demolish, they established criteria, mostly related to the building's and environment's significance (values), as well as, its condition (physical). Only 4 students concluded that the buildings must be rehabilitated, independent from the previously mentioned parameters.

Before being exposed to RE-ARCHITECTURE, the lifespan consciousness of the students about ecological aspects was very limited. For example, in the topic "importance of rehabilitation" (A2.6), the ecological aspect is mentioned only by one student. Moreover, the students, who participated in rehabilitation designs before their contact with RE-ARCHITECTURE, did not make any reference to this aspect. Inversely, in Questionnaire A3, a different opinion raises with respect to lifespan / ecology aspect. When asked about the influence factors in the design, the ecological aspect (sustainability) is the most mentioned one. However, there are still some incongruencies of principles when comparing what they describe as the design's advantages, as the ecological concerns appears in the last place and they attribute more value to the memory preservation and to the new functions attribution, just as they previously answered in the questionnaire A2 (A2.6). For this reason, it was considered that even if a lifespan consciousness was generally raised, most students did not value the importance of the ecological aspect, as much as other aspects implemented in their designs. Only one student made the respective correlation and mentioned the ecological subject as the main reason of success of his proposal. So, it can be concluded that this is still a field to research and implement in an effective way.

About the final destination of the subtractions, generally they opted to recycle the subtracted concrete and use it again in the construction of new elements. However, three students choose for design solutions which resulted in less consumption of resources (energy, material time, etc.); when relocating subtracted components (e.g. concrete walls, metal frames, etc.) directly in the building and / or in its environment. Without doubt, recycling is already better than incinerating and/or landfill. A progress was also perceived at this level, even if not substantially considerable. However, facing their initial level of lifespan consciousness, this short evolution was considered a positive one. An effort was made by most of them to understand all this aspects related with rehabilitation and sustainability, than can certainly be improved in the future.

The results have also shown that the students considered RE-ARCHITECTURE important for their rehabilitation designs (A3.4). Evidences can be found for this statement, when students point out as factor of interest in their design: the curiosity to work with the theorised design process. According to the students, RE-ARCHITECTURE contributes for a more systematized design process, dividing the work in phases, which allows them to organize better their own design processes. It gives orientations and suggestions about the information, which must be collected in each phase, pointing out the most important topics to study, saving them time.

Moreover, they considered that such theorised design process promotes the deep study of several aspects involved in a rehabilitation design process, which allows future raises of lifespan consciousness on all decisions taken during the design process. Accordingly, RE-ARCHITECTURE showed the importance to design, taking into consideration the ecological aspect. So, was verified RE-ARCHITECTURE as a useful way to approach the rehabilitation design process and to supply architects and students with theoretical knowledge and tools that can sustain their raise of lifespan consciousness.

REFERENCES

EC (1999). COM()97 539, Competitiveness of the construction industry – action plan, quoted in Sustainable Construction – final report, European Commission: DG Enterprise, available at: http://www.europa.eu.int/comm/enterprise/construction/suscon/finrepsus/sucopref.htm (accessed on 25-06-2007)

Pereira Roders, A. (2006). RE-ARCHITECTURE: Lifespan rehabilitation of built heritage (scapus), Eindhoven: Technische Universiteit Eindhoven

A framework to sustainable renewal of existing building stock in Brazil

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ABSTRACT: Construction is a key sector to contribute for the sustainable development. Firstly, it consumes a high level of natural resources and energy to produce materials and components. On the other hand, its different processes, as building operation and maintenance, generate a large amount of waste. The adequate specification of materials, construction techniques and management systems in design process can contribute in terms of reducing environmental impact. However, the impact of these improvements in new constructions is slow. Due the construction product long-life and the large quantity of existing buildings it is very important to give special attention to the existing constructions, identifying the potential of improvement through programs of sustainable renewal. In this sense, this work proposes a framework to be used as a decision support system by designers to propose sustainable building renewal.

1 INTRODUCTION

1.1 *Sustainability*

The concept of sustainable development appeared in 1987, with the publication of the United Nations' report "Our Common Future". This study criticizes the model of economic growth adopted by the countries of the North hemisphere. It also defends a new position, aiming to keep the progress and expand it for other countries, at the same time, to reduce the impact on the environment (WCED, 1987). This concept became popular by two UN world-wide conferences on environment, Rio-92 (UN, 1992) and the Rio+10 (UN, 2002). In the same direction, the International Council for Research and Innovation in Building and Construction (CIB) presented the "Agenda 21 on Sustainable Construction", with a special version for develop countries (Plessis et al., 2002). This document confirms the importance of the construction industry in the issue of sustainability (CIB, 1999).

The sustainability is generally analyzed through three basic aspects that must be reached jointly, in a coherent form: environmental, economic and social. According to the Rio-92 conference, the sustainable development may be based on three principles: (a) complete material life cycle assessment; (b) development and use of renewable raw materials and energy; and (c) reduction of the amounts of materials and energy used in the extraction and exploration of natural resources, and the recycling or final destination of the residues (Gauzin-Müller, 2002; UN, 1992).

1.2 *Construction and sustainability*

The question of the construction sustainability is associated with the general sustainability, including the problems of degradation of the natural ambient, changes of the climate and greenhouse effect (Gauzin-Müller, 2002).

The urban constructions represent an important parcel of gases emissions, generation of liquid and solid residues, as well as an expressive consumption of energy, water and site use (Gauzin-Müller, 2002). Moreover, the construction industry consumes 40% (in weight) of the materials used in all the global economy (Yeang, 2001). According to CIB (1999), the European Union constructions are responsible for more than 40% of the energy consumption and it generates 40% of the residues produced for the man. Regarding the Brazilian reality, studies by Loturco (2004); Pinto (1989, 2005), and Rocha & John (2003) point out that the amount of building waste ranges in several cities from 230 to 760 kg/person/year. The challenges of the sustainable construction can be synthesized by efforts considering pro-active and reactive approaches.

In a pro-active way, it is very important the use of sustainable principles to developed new construction projects. This is an ample question, and involves the definitions or decisions to be took since the design process, with respect to materials, construction techniques and building systems, among others elements. For instance: to improve the management and organization of the building site, to optimize the characteristics of the building aiming to diminish the consumption of resources, and to reduce the waste generation, to take into consideration the impact of the construction, regarding a sustainable urban development (CIB, 1999; Plessis et al., 2002).

On the other hand, it is not enough to develop criteria only for the new projects. The potential impact reduction of improvements must also be taken regarding the existing buildings. In general, construction buildings are durable goods and can reach 100 years of useful life or more. However, over the time the quality of the use decays significantly and the economic useful life is lesser. In many Brazilian cities, for instance, a great part of the constructed environment is outdated, as a result of the technology evolution, new standards (for example, fire protection standards), and due to the changes of the user satisfaction requirements. In this context, building renewal can extend the use of the existing buildings with diverse benefits. Two clear benefits are the exploitation of the existing urban infrastructure (with no need for new site development) and another one is the lesser generation of residues in relation to a totally new construction.

1.3 *Sustainable design*

A very important step to sustainability in construction is the sustainable design (or Ecodesign), that is considered as an evolution of the bioclimatic design (Yeang, 2001; Kibert, 2006). According to Yeang (2001), the benefits of the sustainable design include reduction of costs, better environmental performance, innovation, new business chances, and better general quality in the buildings. The sustainable design considers the use of recycled, reused or reintegrated materials, as well as it wishes low environmental impact choosing materials following the general requirements of the bioclimatic design (low energy consumption, for example). One of most evident tool to support sustainable design is life-cycle assessment (LCA). LCA is used by designers to evaluate the impact of the building (*i.e,* material, techniques) regarding the life cycle of the project.

Bioclimatic or sustainable design studies by the view point of new projects are widely discussed in the literature (Anderson & Wells, 1984; Camous & Watson, 1986; Edwards, 1998; Herzog, 1996; Gauzin-Müller, 2002; Olgyay, 1998; Yeang, 2001; Wooley et al., 1998). However, there is a lack of research studies regarding adaptation and improvement of existing building in terms of sustainability. In face of this context, this work proposes a framework to be used as a DSS by designers in sustainable building renewal. The proposal is based on three active components: Life cycle assessment (including the analysis of environmental costs and alternative material and building techniques), hedonic price models (verifying economic aspects) and post-occupation evaluation (to better consider the client's requirements). Other element to be included is knowledge about recycled materials. It also includes law and urban/social rules and construction management aspects.

2 PRODUCT RENEWAL DESIGN FRAMEWORK PROPOSAL

2.1 *Decision support system*

The main idea of the framework proposal of this study can be described as a Decision Support System (DSS) to improve decision making in AEC design process of product renewal, considering sustainability approach through three dimensions: environmental, social and economics aspects. These three aspects may form an information database that will help designers to propose product renewal design. This database can be very helpful especially because sustainable aspects are new and the client's objectives and design requirements are dynamic in nature. A framework of DSS model is described by the cycle presented in Fig. 1.

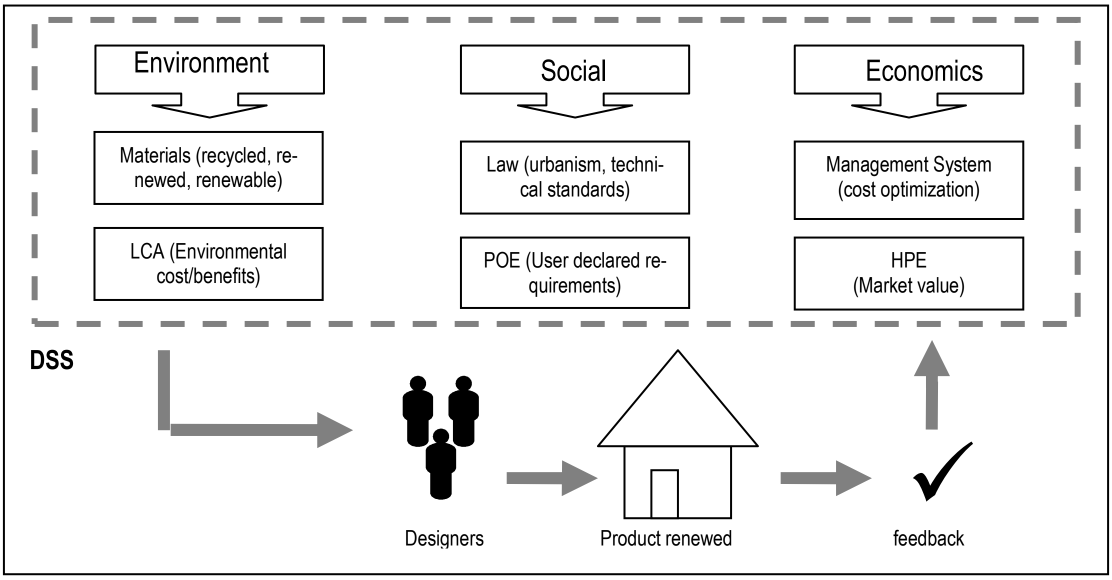

Figure 1 – Configuration of a decision support tool to sustainable renewal

A Decision Support System can be viewed as a knowledge discovery task, for example, obtaining user and buyer knowledge. Knowledge discovery in databases (KDD) is a valuable tool to improve the intelligence of building renewal design process. It consists of a special data and techniques organization to allow knowledge revelation of that presumably is occult in data, which represent real situations. This research area appeared in the end 80's, as an alternative for the analysis of great databases (Fayyad et al., 1996). The knowledge discovery occurs through different phases, with two main process stages: data preprocessing and data mining. The preprocessing phase uses several statistical techniques, such as clustering, regression analysis, and descriptive statistics. In the data mining phase the analyst choose adequate techniques to develop the solution. In general, KDD is developed using a set of Artificial Intelligence tools (Berry and Linoff, 2000; Soibelman and Gonzalez, 2002).

A system based on dynamic knowledge has an advantage upon Expert Systems - model-based reasoning (ES). In the last years, several ES have been developed, with an explicit model of the problem domain in which they operate. However, there are two main problems with ES: such systems are very complex and take many effort to develop ("knowledge elicitation bottleneck"), and once developed they are difficult to maintain (Watson and Abdullah, 1994).

In this case, case-based reasoning (CBR) is used as a tool to improve the access of available knowledge to designers, by an intelligent way. It can be described as a problem solution technique, based on knowledge, adapting and reusing previous experiences (synthesized in "cases"). The basic idea is to make use of old solutions while solving a new problem (using experience). In other words, it is a technique that considers solutions for new problems, based on previous problems solutions, identified in a database through a mechanism of cases election. If the problems are distinct, it is assumed special importance on the adaptation mechanism (Aamodt and Plaza, 1994; Watson, 1997). The main advantages of this technique include the fact that the method does not depend on an explicit model for the problem solution. It has flexibility to work with great data amounts and it is possible to learn with new cases, being easy to keep brought up to date the system (Watson, 1997). The reasoning based on cases is a cyclical process, composed basically by four phases: (a) recovery of similar cases, (b) reuse of the information as proposed solution, (c) revision of the solution, and (d) retention of the experience for future use (Aamodt and Plaza, 1994).

Some studies demonstrate the use of KDD and CBR in civil engineering. Soibelman and Kim (2002) presented a prototype to knowledge discovery in a U.S. Army Corps of Engineers database, searching construction delays explanation. Ng & Smith (1998) presented a DSS to contractor prequalification using CBR, considering client requirements such as schedule, budget and quality standard. Watson and Abdullah (1994) develop a CBR system applied do diagnosing building defects. Oliveira et al. (1997) presented an environment to training and learning scaffold structures using virtual reality and CBR.

In a complementary direction, the vision of the designers and the users does not coincide necessarily. In many cases, the design process of the constructions is carried through without the user participation. If the involved professional does not know well the user necessities and preferences, there is a great risk to be developed an inadequate project. This fact probably will generate discomfort or provoke reforms throughout the project life-cycle, generating building waste or excessive energy consume. There are two ways to obtain knowledge about user's preferences, through market analysis techniques, for instance, using post-occupancy evaluation (POE) and hedonic price models (HPM), described as follow.

2.2 *Environmental aspects*

Life cycle assessment (LCA) is a useful technique that regards materials and energy involved in a product, process or activity. It also considers environmental impact measurement. This is aligned with the subject discussed in Rio+10 conference, in terms of what must be the actions in plan: "To develop politics of production and consumption in a way to improve the products and services offered, reducing the ambient impacts, using, when appropriate, scientific boarding, such as the evaluation of the life cycle" (UN, 2002).

LCA is an ambient evaluation process associated with a product, process or activity, through the identification and quantification of energy and materials used in the production, and the residues generated. In other words, it evaluates the impact from these elements on the environment. Moreover, it also requires the identification and evaluation ways of environment improvements in this sense. This analysis includes the product, process or activity life cycle, including extraction, raw materials processing, production, distribution, use, reuse, maintaining, recycling and final disposal.

There are four interactive phases for the development of the study of the life cycle assessment, described as follow:

- Planning: it defines the goals and objectives of the LCA, including the limits of the inquiry, beginning and end of the study;
- Analysis of inventory: it searches a quantitative analysis of the inputs and outputs of the product or system, consisting in evaluation and measurements of the expenses in energy, raw materials, residual emissions of gases, water and solid residues;
- Evaluation of impact: it evaluates how the product or system affects the environment, adopting a qualitative and quantitative boarding to analyze the consumption of materials, energy, water and the emissions of gases and generation of solid and liquid residues affect the environment;
- Analysis of improvements: it involves the study of improvements to reduce the impacts all associates with the product or system through an objective vision of the cycle of life and the evaluation of the impact that these changes can provoke in the environment.

The use of LCA in Brazil is still incipient and it is necessary a specific data-collecting for the Brazilian reality, since the building design and production process used in Brazil (including material, construction techniques and specifications) are distinct from countries that already possess LCA studies. In face of that, Silva (2003) demonstrated that LCA methods used in other countries may be not adjusted for Brazil, and he defended that it is very important to develop adequate techniques to the Brazilian conditions.

LCA also can be very useful for Brazilian construction industry, like it is in several countries, mainly in the European continent. The building design is determinative in terms of environmental impacts provoked. Not only during the construction phase, but also, and mainly, during the long phase of building use. Thus, the application of "life-cycle thinking" in design process can contribute decisively for the environment preservation.

However, the development of LCA studies is more difficult in the construction industry, because some typical construction characteristics, such as contract informality, cost aspects, large number of medium and small companies, among others. Because of that, construction industry is delayed in relation to other industries. It has some small studies in Brazil, such as Cybis and Santos (2004) on masonry, Manfredini and Sattler (2005) on red ceramics, and Taborianski and Prado (2003) on water heating, but still it has a long way to tread.

The use of new materials and techniques, such as forested wood or reused materials is also a good option to reach sustainability. For example, in Brazil, Stumpp et al. (2006) demonstrated the use of natural treatments of forested woods, and Kazmierczak et al. (2000a, 2000b, 2000c) present a study in reuse of shoe materials in construction. This kind of information need be in a DSS to design purposes.

2.3 *Economic aspects*

Inadequate management systems are said to be the major cause of the construction industry inappropriate development. Although important initiatives were made, as pre-fabrication and modularization, real benefits from them are still incipient and not clear. Authors as Koskela (2000) and Bertelsen (2002) suggest that the lack of a management theory has been a strong barrier for the sector progress.

According to Koskela (2000), one of the causes of the ineffectiveness of traditional construction management systems is the fact that production is viewed basically as a transformation process. This is a very simplistic view and it fails to consider waste generation during the production process and the client requirements properly during the design process.

From the production process perspective, it does not explicitly consider the non value-adding activities, which tend to be neglected in production control, despite their high impact in terms of cost and waste. According to Shingo (1988), minimizing waste must be the central element in the development of the production process. This requires that different ways of waste must be identified to be avoided as much as possible. This author exposes seven types of waste, often generated in a production process: (a) overproduction; (b) correction; (c) material movement; (d) processing; (e) inventory; (f) waiting; and (e) motion.

From the design perspective, Koskela (2000) points the importance of keeping the focus on the client requirements during all the process of development of the product to better meet customer demand to generate value-added-product. In essence, the value of a product can be determined only in reference to the customer, and the goal of production is satisfying customer needs. It is not the transformation of raw materials in a final product itself that is valuable (focus of traditional management systems), but the fact that the output corresponds to the requirements and wishes of the customer. For instance a well done product may be inappropriate – to make right a wrong product. In this context, Koskela (2000) proposes five principles to be taken, specially by designers, in order to create value added products: (a) to ensure that all customer requirements (explicit and latent) have been captured; (b) to ensure that relevant customer requirements are available in all phase of production, and that they are not lost when progressively transformed into design solutions, production plans and products; (c) to ensure that customer requirements have a bearing on all deliverables for all roles of the customer; (d) the capability of the production system to produce products as required; (e) to ensure by measurements that values is generated for the customer.

Another important issue is materials transport. Brazil is a large country, then distance for transportation and its correspondent cost are relevant. For example, in some regions there are not exist sand, in other the problem is stone, which need to be transported by road for 200km or more. In view of sustainability, the use of recycled construction waste in substitution to these materials is a good option.

However, client requirements information is not always available for the designer, especially during the early phase of the project. In many times, the requirements are carried through an intuitive form, following the entrepreneur feeling. However, the initial phases, that involves the project conception and planning have a great impact potential on the final cost, as well as on the value generation. This fact makes a decision support system very helpfully, through analysis mechanisms that systemize the available information, aiming to better reach the customer requirements, resulting in a value-added-product. It also can help designers and constructors in finding materials and suppliers regarding sustainability aspects.

Building renewal design can also be improved by using market models, such as hedonic price models (HPM). Properties are considered economically as composite goods, regarding the simultaneous influence of diverse characteristics that affect the price formation. These models have the objective to estimate the market value of the property, through the analysis of the influence of each important characteristic using a sample of data of transactions in the segment of interest. It is very helpful since there are a great variety of products in the real estate market. Among others differencing elements, properties have significant variations of design, such as size, configuration of environments and quality of construction, which are reflected in variations in the market prices. Its different localization and property singularity itself make it difficult the direct comparison (Lavender, 1990; Robinson, 1979).

Hedonic price models search to establish the relationship between the practiced price and the diverse characteristics of the property. In the hedonic models, the goods are described through a "bundle of attributes", congregating the characteristics that are important. As the referring parcels to each attribute they cannot be isolated, therefore it does not have specific markets for each one, and prices are gotten indirectly, in general through of multiple regression analysis. The implicit prices of each one of these attributes, also called hedonic prices or "shadow prices", are the prices related with each one of the attributes of the property, such as size, age and location (Rosen, 1974; Sheppard, 1999).

The detailing of these models is carried through in function of the interests of the study. HPM can be used for evaluation of property, taxation and studies of conception of constructions, through the prediction of values for diverse alternatives of interest. Through the MHP they can be identified to the values added for project decisions, representing the potential of market for these alternatives. In such a way, comparing these values with the corresponding costs (gotten through budget processes), the economic viability of these alternatives can be identified. This technique can be used to decision-making among available options in building design.

2.4 *Social aspects – users*

The post-occupancy evaluation (POE) is one important technique to identify problems and positive points to feedback designers about design decisions. It is composed by an ample diagnosis of the constructed environment, including analysis of the constructive system, ambient comfort, functionality, accessibility, security against fire and relations of the environment constructed with the user. This analysis is usually carried through a set of methods and techniques for data collection, as such as interviews and field surveys, and data analysis techniques as results tabulation and mapping, aiming to identify differences between the final project and user requirements and necessities (Kowaltowski et al., 2006; Voordt & Maarleveld, 2006; Watson, 2003).

As a main advantage, results from POE may be use by designers to develop new project design, considering positive and negative aspect pointed by users, improving the design process forwards. For Kowaltowski et al. (2006), the employed techniques must consider behavioral evaluations, and also, physical, evaluations measurements, assays, archetypes analysis and general comments.

Other important question to be incorporated in building design is the social regulation, defined by general law and urban rules. Real estate market functioning depends of legal standards about property and of urban management practices. Brazilian cities face several problems in the urban areas, such as scarcity of good public services, inequality of property taxes, inefficient urban planning and management practices, and lack of social land and housing. In recent times, it was launched a new federal law on urban policy, called City Statute. This new regulatory standard has created some new instruments, which were added to existent ones, performing a large set of legal instruments. There is great potential for improve urban planning, both from a fiscal and non-fiscal viewpoint. Probably it will have a strong influence on real estate market, especially on land market. Besides that, Brazilian medium and large cities must have (by law) urban development plans and construction rules, including a set of construction technical norms.

3 CONCLUDING REMARKS

Building renewal is an important strategy to reduce environmental impact of construction industry. Part of this question is about building material and techniques, assessed by LCA tools. In other sense, a better design, more adjusted to client requires (buyer and user views), also can contribute to reduce environmental impact. This paper presented a framework to knowledge extraction, with the objective of improve building renewal design. The system is in knowledge acquisition stage, searching for construct the database. In sequence, it is necessary to validate knowledge and to develop a weighting mechanism to make easy designer decision making.

REFERENCES

Aamodt, A. & Plaza, E. 1994. Case-based reasoning: Foundational issues, methodological variations, and system approaches. *AI Communications*, v.7, n.1, p.39-59, Mar.

Anderson, B. & Wells, M. 1984. *Guia facil de la energia solar pasiva*: Calor y frio natural. Mexico: Gustavo Gili,

Andrade, C.M.; Leite, B.C.C.; Ornstein, S.W.; Maleronka, C.G. 2002. Avaliação pós-ocupação (APO) aplicada em edifício antigo requalificado para abrigar centro de teleatendimento 24 horas. In: *IX Encontro Nacional de Tecnologia do Ambiente Construído*. Foz do Iguaçu: ANTAC.

Berry, M.J. & Linoff, G. 2000. *Mastering data mining*. New York: Wiley Computer Publishing.

Bertelsen, S. 2002. Bridging the gaps – towards a comprehensive understanding of lean construction. In: *X Annual Conference on Lean Construction*. Gramado (Brasil): IGLC.

Camous, R. & Watson, D.S. 1986. *El habitat bioclimatico:* De la concepción a la construcción. Mexico: Gustavo Gili

CIB (International Council for Research and Innovation in Building and Construction). 1999. *Agenda 21 on Sustainable Construction*. CIB Report Publication n.237. Rotterdam: CIB.

Cybis, L.F. & Santos, C.V.J. 2000. Análise do ciclo de vida (ACV) aplicada à indústria da construção civil - estudo de caso. In: *XXVII Congresso Interamericano de Engenharia Sanitária e Ambiental*, Porto Alegre (Brasil): AIDIS-ABES/RS.

Edwards, B. (Ed.). 1998. *Green buildings pay*. London: E&FN Spon.

Fayyad, U.M.; Piatetsky-Shapiro, G.; Smith, P. 1996. From data mining to knowledge discovery: An overview. In: U.M. Fayyad; G. Piatetsky-Shapiro; P. Smyth; R. Uthurusamy (Eds.). *Advances in knowledge discovery and data mining*. Menlo Park (CA)/Cambridge (MA): AAAI Press/MIT, p.1-34.

Gauzin-Müller, D. 2002. *Arquitectura ecológica.* Barcelona: Gustavo Gili.

Herzog, T. (Ed.). 1996. *Solar energy in architecture and urban planning*. Munich: Prestel.

Kazmierczak, C.S.; Kern, A.P.; Santos, I.S.S.; Ramires, M.V.V.; Silva, H.C. 2000a. Gypsum matrix composites with shoe counter scrap - Impact strength behavior. In: *CIB Symposium on construction & environment - Theory into practice*. São Paulo: PCC-USP/CIB.

Kazmierczak, C.S.; Kern, A.P.; Santos, I.S.S.; Silva, H.C.; Ramires, M.V.V. 2000b. Use of waste generated by shoe counter scrap pieces in plaster of Pris composites. In: *Science and Engineering of Recycling for Environmental Protection - WASCON 2000*, p. 848-856. London: Pergamon.

Kazmierczak, C.S.; Santos, I.S.S.; Silva, H.C.; Ramires, M.V.V.; Kern, A.P.; Silva, M.E. 2000c. Biodeterioration of plaster of Paris and shoe counter scrap pieces composites. In: *1st International RILEM Workshop - Microbiological Impact on Building Materials*. São Paulo: USP - RILEM.

Kibert, C.J. 2006. Revisiting and reorienting ecological design. In: *Construction Ecology Symposium*. Cambridge: MIT.

Koskela, L. 2000. *An exploration towards a production theory and its application to construction*. Thesis (Doctor of Technology, Technical Research Centre of Finland). Helsinki: VTT.

Kowaltowski, D.C.C.K.; et al. 2006. Reflexão sobre metodologias de projeto arquitetônico. *Ambiente Construído*, v.6, n.2, p.07-19, abr./jun.

Lavender, S.D. 1990. *Economics for builders and surveyors*. Essex (UK): Longman.

Loturco, B. 2004. A Nova Lei do Lixo. *Téchne*, n.82, p.52-55, Jan.

Manfredini, C. & Sattler, M.A. 2005. Estimativa de energia incorporada a materiais de cerâmica vermelha no Rio Grande do Sul. *Ambiente Construído*, v.5, n.1, p.23-37, jan./mar.

Ng, T. & Smith, N.J. 1998. Verification and validation of case-based prequalification system. *Journal of Computing in Civil Engineering*, v.12, n.4, p.215-226, oct.

Olgyay, V.W. 1998. *Arquitectura y clima:* Manual de diseño bioclimático para arquitectos y urbanistas. Barcelona: Gustavo Gili.

Oliveira, L.R.; Retik, A.; Watson, I. 1997. The integration of VR and CBR to visually represent past experiences. In: M. Heinisuo (Ed.). *Application of artificial intelligence in structural engineering - IV*, p.105-116, oct.

Pinto, T.P. 1989. *Perdas de materiais em processos construtivos tradicionais.* São Carlos: UFSCar.

Pinto, T.P. 2005. *Gestão Ambiental de Resíduos da Construção Civil*. A experiência do SindusCon-SP. São Paulo: ObraLimpa: I&T: Sinduscon-SP.

Plessis, C. Du; et al. 2002. *Agenda 21 for Sustainable Construction in Developing Countries*. Pretoria: CIB & UNEP-IETC, v.1.

Robinson, R. 1979. *Housing economics and public policy*. London: MacMillan.

Rocha, J.C. & John, V.M. (Eds.). 2003. *Utilização de Resíduos na Construção Habitacional*. Porto Alegre: ANTAC.

Rosen, S. 1974. Hedonic prices and implicit markets: product differenciation in pure competition. *Jornal of Political Economy*, n.82, p.34-55.

Sheppard, S. 1999. Hedonic analysis of housing markets. In: CHESHIRE, P. C.; MILLS, E. S. (Eds.) *Handbook of applied urban economics*, v.3. New York: Elsevier, chap.8.

Shingo, S. 1981. A study of Toyota production system from an industrial engineering viewpoint. Toquio, Japan Management Association.

Silva, V. G. 2003. *Avaliação da sustentabilidade de edifícios de escritórios brasileiros*: Diretrizes e base metodológica. Tese (Doutorado). São Paulo: USP.

Soibelman, L. & Gonzalez, M.A.S. 2002. A knowledge discovery in databases framework to property valuation. *Journal of Property Tax Assessment and Administration*, v.7, n.2, p.77-106.

Soibelman, L. & Kim, H. 2002. Data preparation process for construction knowledge generation through knowledge discovery in databases. *Journal of Computing in Civil Engineering*, v.16, n.1, p.39-48, June.

Stumpp, E.; Rech, V.; Sattler, M.A.; Barros, N.M.; et al. 2006. Avaliação de sustentabilidade e eficácia de tratamentos preservantes naturais de madeiras de florestas plantadas no RS para o controle do cupim.. *Ambiente Construido*, Porto Alegre, v.6, n.2, p. 21-31.

Taborianski, V.M. & Prado, R.T.A. 2003. *Avaliação da contribuição das tipologias de aquecimento de água residencial para a variação dos balanços de gases de efeito estufa na atmosfera*. São Paulo: EP-USP.

United Nations (UN). 1992. *Report of the United Nations Conference on Environment and Development* (RIO´92- The Earth Summit). Rio Declaration on Environment and Development (Annex I). New York: UN.

United Nations (UN). 2002. *Plan of implementation - Conference on Environment and Development* (Earth Summit 2002 - Johannesburg). New York: UN.

Voordt, T.J.M.& Maarleveld, M. 2006. Performance of office buildings from a user's perspective. *Ambiente Construído*, v.6, n.3, p.7-20, jul./set.

Watson, C. 2003. Review of building quality using post occupancy evaluation, *Journal of the Programme on Educational Building*, Paris: OECD.

Watson, I. 1997. *Applying case-base reasoning*: Techniques for enterprise systems. San Francisco: Morgan Kaufmann.

Watson, I. & Abdullah, S. 1994. Diagnosing building defects using case-based reasoning. In: *Tokyo Symposium on Strategies and Tecnnologies for Maintenance and Modernisation of Buildings (CIB W70).* Tokyo: CIB.

World Commission on Environment and Development (WCED). 1987. *Our common future* ("Brundtland Report"). Oxford: Oxford University Press.

Wooley, T.; Kimmins, S.; Harrison, P.; Harrison, R. 1998. *Green building handbook:* a guide to building products and their impact on the environment. London: E & FN Spon.

Yeang, K. 2001. *El rascacielos ecológico.* Barcelona: Gustavo Gili.

Sustainability and natural resources uses at a South Brazilian university: proposing an environmental plan to University of Passo Fundo

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ABSTRACT: The Higher Education Institutions through its physical structure, in isolated buildings or in a campus, allow the evaluation of the urban and environmental impact by a sustainable assessment. This research shows the actual usage of the natural resources in the buildings of Universidade de Passo Fundo – UPF, related to the aspects of water and energy consumption, and the management of solid and liquid residues, reinforcing the university role in the sustainable development, and, at the same time, allows the inclusion of UPF in the "ECO-CAMPUS" group, it means, universities which look for their own sustainability in all of their daily activities (Education, research and management). Therefore, must contribute for a diagnostic of the conditions of the whole building stock of the University, through the application of a methodology according to the principles of the Environmental and Energy Audit.

1 INTRODUCTION AND OBJECTIVES

University has an environmental responsibility by its knowledge and professional practice, following the principles of the UNESCO Decade of Sustainable Education for 2005-2014 (UNESCO, 2004). The practice on sustainability on university ranges since the evaluation of its campuses and buildings by a sustainable assessment, the application of a defined criterion to action until, finally, the inclusion of the whole university community. The implementation of a proper Environmental Management System (EMS) is a feasible tool to define the objectives and policies on this issue.

As a part of the EMS, the Energy and Environmental Audit can provide an overview of all input and output materials and energy flows. Based on this analysis, it will be possible to define which aspects need to be optimized, in order to achieve the efficiency on the management of natural and economics resources.

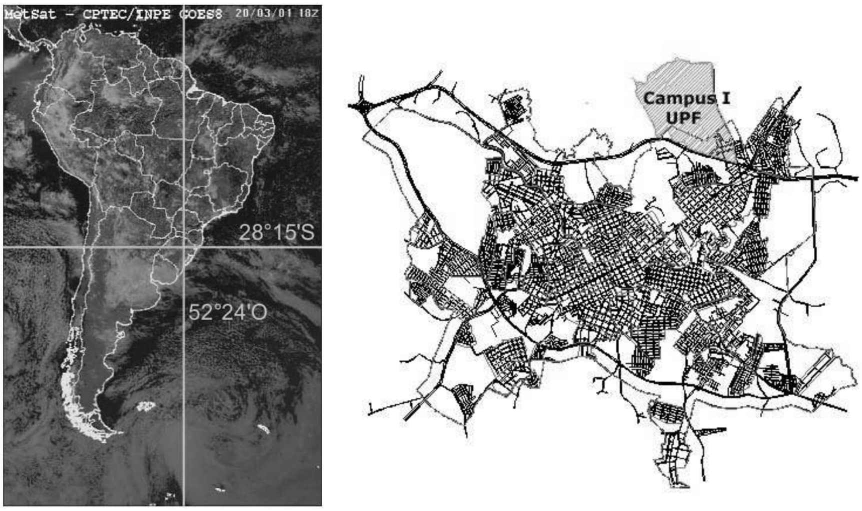
This paper is a partial result of the research being developed on the Architecture and Energy Ph.D. program of Polytechnic University of Catalonia (UPC), Barcelona, called "A methodology to include the energy efficiency in the universities buildings: environmental and economics considerations".

The study proposes an evaluation of the recent proceedings and methods adopted by the UPC to include the sustainable principles at the UPC's Master Plans, following some previous researches (Frandoloso & Cuchí i Burgos & López Plazas, 2006) developed in the framework of REAL Laboratory - CITIES; with the objective of propose a methodology to integrate all aspects involved in the energy consumption of buildings at universities centres.

Besides the UPC, the methodology is being applied to another context with same characteristics of use, in this case to the South Brazilian University of Passo Fundo (UPF). The application is being accomplished based on the contextualization of climate, cultural, social and economy situations.

2 UNIVERSITY CONTEXT AND BUILDING STOCK

The research is being developed on the Universidade de Passo Fundo (UPF), a multicampi university, i.e. with a regional structure formed by 7 campuses around Passo Fundo, a medium-sized (about 170 000 inhabitants) in the Southern Brazil, as shown in Figure 1.



Figures 1- 2. Passo Fundo and UPF Campus I locations.

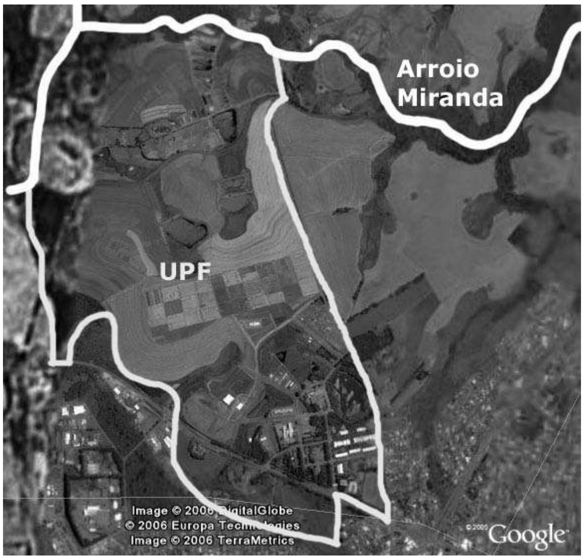
The main campus (Campus I) occupies an area of 341 ha; in 2006 the built area was 107.643 m² receiving a population of 17 603 students and 2 078 teachers and staff.

The climate conditions in Passo Fundo indicates a warm summer (112 cooling DD, base 23ºC) and cold winter (857 heating DD, base 18ºC), indicated to passive solar strategies to cooling and heating. The application of Givoni’s building bioclimatic chart (BBCC) shows: during 29.1% of the year there are comfortable conditions, while cold in 57.5% and hot in 13.4% (Frandoloso & Cuchí i Burgos, 2005).

Figures 3. UPF Campus I neighbourhood.

The Campus 1, in 1968, was located outside the urban area, following the Anglo-Saxon model of university planning which dominated in Brazil in the 60’s and 70’s years. The campus was situated far from residential zones, in the convergence of national roads as presented in Figure 2. In the last decades the number of inhabitants increased and nowadays the campus boundaries are coincident with an area occupied by medium-class housing, service buildings and commercial area (see Figure 3).

As showed in Figure 4, the campus surroundings, besides the housing and commercial neighbourhood on South-east and South limits, are composed by natural environment - the Miranda River is an important water supplier to the city - and farms on the East, North and West limits.



Figures 4. UPF Campus I boundaries (adapted of DIGITAL GLOBE, 2006).

Regarding the consumption of energy in the buildings, the control system is centralized in a unique unit consumer, with its management in charge of the Section of Conservation of the Campuses. In the present moment, the responsible sector is working with the proposition of some strategies for the decentralization and monitoring the consumption.

According to an administrative study, performed in June of 2005, the costs of the electric energy presented a "significant increasing, around 35% (concerning of taxes and tariffs) ..."; From this verification, were suggested the necessaries steps aiming the energy economy through the collaboration of all users, such as the turning-off of lights when the spaces will be without users and of equipment and computers in schedules of break.


Figures 5-6. UPF Building stock: original and latest construction systems.

During the almost 40 years of the campus, different types of construction has been employed: the first one was a current system, built with single-brick masonry walls, a 15 mm expanded polystyrene ceiling and a pitched-roof of asbestos cement tiles (Fig. 5), without a proper thermal mass and consequently without comfort conditions; recently had been adopted by the project staff double brick walls and concrete ceilings, and was increased in some projects shading devices to control solar radiation and natural lighting (Fig. 6).

Besides the lack of a global environmental plan, some isolated strategies are being improved to achieve sustainable principles at university buildings and campus, for instance:

a. the construction of a wastewater treatment anaerobic chambers to 18 000 people, in operation since September 2006;

b. since 2003 is recollected selectively the solid waste (54.104 ton. in 2005), nowadays it is donated to Citizens Committee Against Hungry and Poverty to commercialize and recycle;

c. rational use of energy with changes of conventional lighting equipment by more efficient ballasts and lamps;

d. energy generation by diesel (to substitute an hydroelectric sources) – 1.45 MW, with the energy supply objective as much for the temporary interruptions by the concessionaire, as much as for the reduction of the consumption in the schedules-peaks between the 17:55 h and 21:05 h, representing an effective reduction of costs around 65%;

e. stormwater management at Technology Centre - CETEC/FEAR (Figs. 7-8).

Figures 7-8. Stormwater management at CETEC/FEAR.

The energy consumption in the Campus I corresponds to 87% of the whole UPF, becoming considerable the control instruments study and energy management and consequently allowing the financial control. The Table 1 shows the variations in the consumption and costs, relative to the years of 2004, 2005 and 2006:

Table 1. Building stock and energy consumption on UPF Campus I.

	2004	2005	variation (05/04)	2006	variation (06/05)
Buit area (m²)	97.320,53	99.067,69	1,80%	107.643,88	7,97%
Energy consumption (kWh)	3.356.236	3.409.882	1,60%	3.442.858	0,96%
Costs (R$)	1.557.562,45	1.912.870,98	22,81%	1.314.777,46	-45,49%

The table 1, also presents an area built in the Campus I, that indicates, although the growing construction and enlargement of the physical structure of UPF (around 8% between 2005 and 2006), the initial measures, already implanted, obtained positive results in the maintenance of the consumption profile, allied to the costs reduction (reduction around 45% in the same period), looking for control procedures adopted in rush hour, for example, the creation of its own energy and the consequently differentiation in the tariff by the energy concessionaire.

3 ENERGY AUDIT

An Environmental Management System – EMS, provides a feasible tool to enable institutions to address environmental effects, by policies and practices on monitoring and evaluation of resources uses and its impacts. For this reason, its development constitutes a way to carry the universities through their sustainable commitment.

According to Viebanh (2002) the University of Osnabrück, Germany, had proposed a systematic approach to reduce the consumption of resources at the university, developing an EMS that should involve all academic community. The plan focuses on recording and modelling the material and energy flows of the University in order to develop an “ecobalance”.

Kibert (2005: 41-42) also mention that the “eco-efficiency” includes environmental impacts and costs as a factor in calculating business efficiency. According him, the World Business Council on Sustainable Development – WBCSD –has articulated seven elements to achieve it, among reducing the energy intensity of goods and services.

As a part of an EMS, the methodology of Energy Audit adopted in this paper identifies and evaluates the buildings and systems characteristics in relation with the energy sources (Diputació de Barcelona, 1986). The study premise is that the energy consumption is related to 3 main factors: the energy demand (building location and building shell); the performance of systems and installations; and the management of use and occupation (intensity and space-time distribution).

This study is based on previous researches developed at Polytechnic University of Catalonia (López Plazas, 2006) that was presented by Frandoloso & Cuchí i Burgos (2006) showing that the management of space uses, systems and infrastructures have a significant influence in the energy consumption.

The analysis is based on two kinds of data: the “static” data are related to the building location (outdoor and indoor conditions), building characteristics (architecture and construction), systems and infrastructure and energy resources.

The second type of data, the “dynamic” data, are obtained modelling the space occupation, the numbers of users, and the kind of activities with the energy performance, through an automatic control of energy consumption.

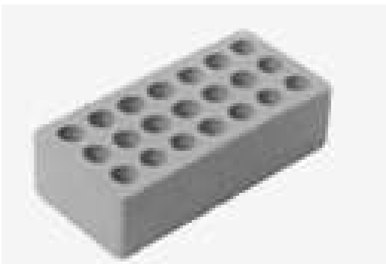
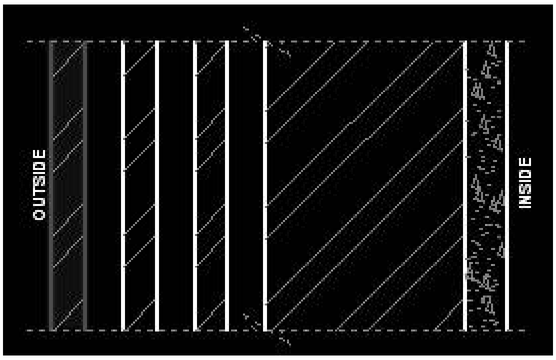

Figures 9-10. Building G1- East and North façades.

Nowadays, this methodology is being applied in two buildings of the Faculty of Engineering and Architecture, representative of the diverse existing constructive typologies in the Campus I of Universidade de Passo Fundo: the building G1, administrative and educative building of FEAR - Faculty of Engineering and Architecture – (Figs. 9-10), and the building L1, of the Sustenance Engineering Course, that counts with laboratories and classrooms (Figs. 11-12).

Figures 11-12. Building L1: Southern and Northern façades.

To the present phase, were elaborated the static facts inventories of the building L1, related to the general characteristics of buildings, and of its internal spaces (constructive and architectural characteristics) and the characterization of the installations, on the other hand, in future phase, the dynamics will be obtained from the consumption monitoring of energy for different uses and following spaces uses and occupations.

G1 was built using the original construction system: 14cm single masonry walls with 21 holes vertical holes (Fig.13a) and internal mortar, with 15mm expanded polystyrene ceiling in the upper floor, shading devices was installed in a recent retrofitting in North-eastern and Northern façades (Fig. 9-10). The L1 was built with 24cm double brick walls (external brick as G1 plus an internal compact brick and internal mortar) – see Fig. 13b, and concrete ceiling, but the windows on Northern façade do not receive any protection to radiation and natural lighting (Fig. 12).

a  b 

Figures 13. Masonry bricks: 21 vertical rounded holes (a) and respective wall layers (b).

The inhabitation conditions monitoring of (temperature and humidity) of the internal spaces is in development (Cunha et al., 2006), also it will be calculated the PMV (Predicted Medium Votes) adopting Fanger's method. In the Table 2 are represented the temperature at the rooms studied, aiming differences of temperatures in the order of 5ºC between classrooms with same North orientation in the two buildings of study: rooms 27 (G1) and LabCa and 103 (L1).

Table 2. Dry bulb air temperatures and relative air humidity by season in L1 and G1 rooms.

Room	27		LabCar		103	
Season	temp (ºC)	humidity (%)	temp (ºC)	humidity (%)	temp (ºC)	humidity (%)
Spring	22.2	51.8	23.9	49.5	25.5	45.6
Summer	23.5	53.3	28.5	48.6	28.4	49.3
Autumn	21.2	57.0	25.5	47.3	25.8	46.1
Winter	20.6	39.2	24.2	46.2	25.1	44.0

In spite of almost the same involving construction, with a U= 1.26W/m²K in G1 and U=1.12W/m²K in L1; thermal properties calculated with ECOTECT (Marsh, 2006), the main difference between those rooms is the heat gain caused by solar radiation: while the 27 classroom have solar protector outside and inside, the room of L1 does not have any solar protection.

The next step of the evaluation will be to collect de dynamic data, it means, the characterization of use, occupation and real resources consumption (energy and water), but in this moment the information is not available to be published yet; these data will be compared with software simulations ECOTECT.

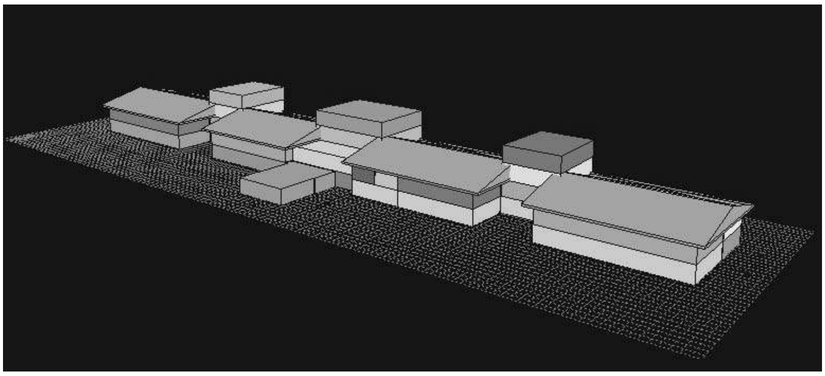


Figure 14. ECOTECT model of L1 building, presenting thermal multi-zone characterization.

The modelling and thermal buildings simulation uses the software (Marsh, 2006) where is possible to define the thermal multi-zones, showed by Figure 14. Besides, this tool presents a graphic interface with an easy adoption in Architecture and permits to export the final dada to ENERGYPLUS (USA - DOE, 2006), step to be developed soon.

Than, the research will be able to provide some criteria in order to improve the building stock, related to better indoor conditions that really correspond to climate conditions, using passive strategies to heating and cooling, and at the same time to improve the efficient and rational use of natural resources, and to reduce the environmental impacts.

At the conclusion of the research it will be possible to improve the method as an operational tool, to help taking decisions during the whole process of design, construction and use of buildings. In the specific case of the application to University of Passo Fundo, the final results of the research will provide elements to propose an instrument to improve the performance of the buildings stock in the campus, also to elaborate the guidelines to the “Environmental Efficiency and Energetic Program” applicable in the whole UPF campuses.

4 FINAL CONSIDERATIONS

First of all, the university has an important potential field to prepare more conscious and responsive professional through knowledge, and especially putting into practice the principles of a sustainable society on its Master Plans and its all activities, in a collaborative and responsible way to involve the whole university community in the imperative process of changing procedures and habits.

The evaluation of universities campuses and buildings through a sustainable assessment and the application of a defined criterion to action can be a practical way to reinforce their environmental responsibility, following the principles of the UNESCO Decade of Sustainable Education for 2005-2014.

Related to the application of Environmental Plans the study shows the importance of a systematic and continuous re-evaluation of the process and the assessment methods.

In the same way, the evaluation of building performance by energy consumption and energy audit results into a practical method to verify the building quality in terms of users' comfort, efficient use of spaces and, in generals aspects, the commitment to sustainable construction.

Related to the management of energy resources, UPF have been shown efficient in economics terms, resulting in a significant reduction of primary costs, but should be analyzed the costs of energy generation using non-renewable fuel, and mainly, its environmental impact.

In spite off some strategies in isolated buildings, the mayor amount do not present comfort condition to face different main seasons (hot and humid summers and cold and humid winters).

The preliminary results show that is necessary a retrofitting of the building stock of Campus I, not only in those built with a low profile construction system that characterize the first buildings, but also in recent one, apparently built with a better thermal properties and, in a first glace, consequently better indoor comfort conditions: the temperatures in December shows that was not taken care about the heat gain by direct solar radiation in hot season or periods, or even the heat lost in the winter.

The energy audit method as part of an EMS applied to universities, constitute a valuable tool to know the real condition of each building in order to propose a concrete plan of actions and investments to achieve the energy efficiency, with a corresponding economic results to the whole building stock.

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REFERENCES

Cunha; E. G. da et al. 2006. Eficiência energética na Arquitetura – o caso da FEAR. In: Mostra de Iniciação Científica: a iniciação científica e a gestão sustentável da biodiversidade, 16, 2006, Passo Fundo - RS. *Anais...* Passo Fundo - RS: Ed. Universidade de Passo Fundo. 1 CD-ROM.

Digital Globe. 2005. *Google Earth*: image 28º13'20" S; 52º23'53" W; 2230 ft. 2006. Google, 2005. Software.

Diputació de Barcelona. Servei del Medi Ambient. 1986. *Auditoria energética II: instal·lacions i edificis*. Barcelona: la Diputació, 304 p.

Frandoloso, M. A. L. & Cuchí i Burgos, A. 2005. Environmental issues on universities campi and its urban contexts, some approaches of South Brazilian region. In: The 2005 World Sustainable Building Conference in Tokyo: action for sustainability, 2005, Tokyo. *SB05Tokyo Proceedings*. Tokyo - Japan: SB05Tokyo National Conference Board: 3356-3361.

Frandoloso, M. A. L. & Cuchí i Burgos, A. & López Plazas, F. 2006. La inserción y la integración de los criterios ambientales en los edificios de la UPC: la introducción del uso como factor determinante del consumo de recursos energéticos In: International Conference on Sustainability Measurement and Modelling, 1, 2006, Terrassa - España. *Proceedings of...* Barcelona: CIMNE. 1 CD-ROM.

Kibert, C. J. 2005. *Sustainable construction: green building design and delivery.* Hoboken, USA: John Wiley & Sons.

López Plazas, F. 2006. *Sobre el uso y la gestión como los factores principales que determinan el consumo de energia en la edificación*. Barcelona, 2006. Tese (Doutorado em Arquitetura) - Departament de Construccións Arquitectòniques I, Programa Àmbits de Recerca en l'Energia i el Medi Ambient a l'Arquitectura, Universitat Politècnica de Catalunya, Barcelona.

Marsh, A. J. 2006. *ECOTECT*. Square One Research. Software. v. 5.5. updated: Sep. 13th, 2006.

UNESCO - United Nations Educational, Scientific and Cultural Organization -. Education for Sustainable Development 2004. *Draft International Implementation Scheme for the UN Decade of Education for Sustainable Development (2005-2014).* Available at: <http://portal.unesco.org/education/admin/file_download.php/Final+IIS.pdf?URL_ID=36026&filename=10994104393Final_IIS.pdf&filetype=application%2Fpdf&filesize=834142&name=Final+IIS.pdf&location=user-S/>. [14 Jan. 2005].

United States of America. Department of Energy. 2006. *ENERGY PLUS*. Software. v. 1.3. updated: April 21th, 2006. Available at: <http://www.eere.energy.gov/buildings/energyplus/cfm/reg_form.cfm>. [25 May 2006].

Viebahn, P. 2002. An environmental management model for universities: from environmental guidelines to staff involvement. *Journal of Cleaner Production*, v.10, issue 1, Feb. 2002, p.3-12.

The service integrated envelope applied for sustainable office refurbishment

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ABSTRACT: With growing consciousness for the relation between facades and energy-consumption and the rising sensibility for sustainability, in the beginning of the 21st century double facades, hybrid facades and decentralized mechanical services have been developed. In a market with rising demands on quality and ecologic/economic sustainability, such as Europe, these principles will increasingly have to be applied for the refurbishment of the enormous number of existing buildings. The author’s research led to different efficient strategies that deal with the complex influencing factors. It aims to develop systemized solutions for varied circumstances to be found in an international market, for which a service integrated façade is a promising approach. In one example the application of such a system is presented. An additional façade layer with integrated HVAC is being applied to an office-high rise built in 1970. Simulations have shown that an energy saving of 75% is possible.

1 INTRODUCTION – THE WAY TO SERVICES INTEGRATED FACADE

Façade construction has been a fast developing technology in the building market. In early 20th century the search for structural slenderness and greater transparency led to the product “curtain wall” (Herzog) (Brooks). Mass customization and possibilities of prefabrication made the construction of pre-cast concrete-slabs possible in the 1960s and 70s. Current façades are based either on post-and-rail systems, related to building technology oriented on craftsmen’s work, or on element systems, which bear more possibilities of industrialized production (Krewinkel).

Figure 1: Post tower Bonn

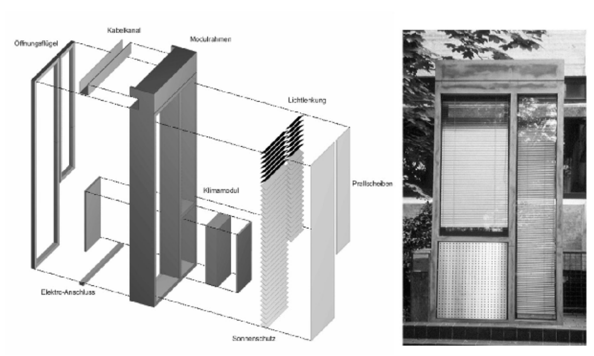

Figure 2: Hybrid façade, developed at University of Applied Science, Germany

With growing consciousness for the relation between facades and energy-consumption in the beginning of the 21st century, research aimed on integration of climate-technology into the façade. This resulted in the development of double facades (Pottgiesser) in the 1990s. The actual development shows the tendency towards total integration of mechanical services into the façade (Oesterle et al.). Climate units with minimized dimensions built either into a façade element or attached at floor level provide all necessary heating and cooling means. Ventilation is achieved by direct connection to the outside. This makes air ducts and installation space within the building obsolete. Two actual examples for service-integrated facades are shown in Figure 1 and 2.

2 FACADE REFURBISHMENT – RESEARCH PROJECT AT TU DELFT

The aim of this research project is to find systematic solutions for the refurbishment of facades for office buildings. The façade serves as an integral part in the building climate concept and thus can not be considered separately. Upgrading the building envelope contributes to more efficiency with limited interference with structure and running work. The main research question is: How is it possible to combine sustainable refurbishment with economic feasibility? It is desired to create an overview of aspects to be kept in mind and present suggestions for systemized façade-refurbishment for real estate dated from 1960 to 1990. The development of systemized solutions suitable for different building types and problems and their verification in case studies form the practical base of this work.

3 ASPECTS OF REFURBISHMENT

3.1 *The market for refurbishment*

The greatest number of office real estate in Europe is dated from the 1960s to 1980s. A study of IFO-institute shows that between 65% of non-housing real estate in Western Europe (agricultural buildings excluded) was built before1978 (Russig). Market-analysis states that in a decreasing market like Western Europe only “grade A”-buildings are lettable. Besides the factors space and location, a modern and economical HVAC is part of this.

3.2 *Energy-consumption*

The mentioned buildings mostly provide a low insulation level and outdated installations. This causes high energy consumption. Round 75% of end energy consumed in buildings of the tertiary sector is used for heating and cooling (Schlomann et al.). Improvements in this aspect can thus lead to big savings both on financial as on ecologic level. The EU directive 2002/91/EC on energy performance of buildings (EU) aimed to raise concern in energy consumption by introducing “Energy Passports” in January 2006. These will be compulsory from mid 2007 and make the running costs of buildings comparable (Poeggeler).

3.3 *Building construction possibilities*

The refurbishment-planning has to deal with existing structure and detailing. The existing substructure, material and connections have just as much influence as fire protection rules, sound protection and energetic demands.

3.4 *Building services*

The big chance in façade refurbishment lies in the possibility to install new building services. Decentralized units mounted in one go with the façade refurbishment require less vertical installations which can be installed relatively easy. Heating, ventilation, cooling and IT-installations can be upgraded without interfering with the interior. This keeps cost short for relocation of staff and renovation of the finishes. Old installations can stay in place disused and can be removed, when it is financially feasible, e. g. on renovation of the interior, demolition or when commodity prices pay back labour cost.

3.5 *Comfort*

The comfort of working staff is an often underestimated factor in productivity. The building skin has to provide the necessary thermal protection in winter as well as in summer, glare-protection, lighting and contact to the outside. Giving people the opportunity to regulate their work environment has proven to contribute enormously to their comfort and productivity [4]. Modern HVAC installations provide the chance for individual exerting of influence. If part of an entire climate-concept they help saving energy and thus money.

3.6 *Aesthetics*

Renovation projects always have to deal with architectural design aspects. Referring to "office grade A" the design and identification with the building are important rental matters. The user demands a representative, individually designed building. Monumental protection rules sometimes also apply to the project and thus impose guidelines to the design.

3.7 *Finance*

In addition to the aspects mentioned above, the financial plan has to contain various other matters. For example there may be the possibility to produce energy with the new building skin. Governments in Europe support renovation-projects by means of grants and favourable tax legislation. The renovation-proposal has to prove on one hand to be more profitable than demolishing and rebuilding, on the other hand it has to provide an economic surplus value in comparison to leaving everything like it is. Only when the refurbishment is feasible there will be the chance to realize a sustainable, energy- and material-conscious building upgrade.

4 DEVELOPMENT OF SYSTEMS

During the research project a market survey has been realized in the Dutch and German building market. Working together with important real estate owners a broad overview of refurbished and to-be-refurbished buildings has been created. Realized refurbishment projects tend to be isolated solutions for single projects, and thus relatively expensive. The main aim of the research is to identify refurbishment-strategies to develop systemized solutions and products. Those shall be applicable and adjustable for different situations.

Renovation principles for office facades can be sorted into two main categories: Single skin solutions; double skin facades fitted from inside and double skin facades installed from outside. Table 1 gives an overview of structural principles and properties, such as the qualitative influence on the energy saving potential, comfort and the aesthetic effect. . The applicability of different levels of installations and the potential of combination with decentralized integrated service units and is evaluated as well.

Overview of systems for facade refurbishment TU Delft, Th. Ebbert, March 2007		Single Skin solutions		Double skin solutions (inside)		Double skin solutions (outside)			
		S1 Replacement of curtain wall	S2 Upgrade by replacement of windows, extra insulation	Di1 Adding of inner exhaust facade	Di2 Adding of inner insulated facade	Do1 Adding of multi storey facade	Do2 corridor facade	Do3 Adding of box-type facade	Do4 HVAC-integrated facade
									
Market / Finance	suitable for	curtain wall with low standards	window-facades	listed buildings with relatively good standards, existing central ventilation	listed buildings, low standards	low and medium height, capable construction	capable construction, intended new HVAC	capable construction, intended new HVAC	medium - high buildings, new HVAC
	Financial aspects	big interference with interior and running work	often the cheapest solution	big interference with interior and running work	big interference with interior and running work	creates a new appearance to the building; little interference with interior	big savings on running cost, little interference with interior	big savings on running cost, little interference with interior	big savings on running cost, little interference with interior, complicated planning, often expensive construction
Construction	Impact on structure	new connections and extra loads	very low	very low	low	Extra load to be suspended (often from roof)	Extra loads brought into floor slaps	Extra loads brought into floor slaps	Extra loads either in roof or floor slaps
	Sound-insulation	depending on glass and components, generally improved	depending on glass and components, generally improved	good	very good	from outside: good; from inside rather bad (cavity)	from outside: good; horizontal noise transport	depending on windows, generally improved	depending on windows, generally improved
	Fire-protection	no changes to existing situation	no changes to existing situation	cavity and ventilation requires special concern	closed cavity requires special concern	danger of rising hot gas in cavity, special means necessary	closed cavity requires special concern	closed cavity requires special concern	danger of rising hot gas in shaft, special means necessary for box-windows
	Impact on interior	very high	very low	low - high	very high	very low	low	low - medium	low - high
Energy		higher insulation, saving of heating and cooling energy, optimal up-to date standards	higher insulation, saving of heating and cooling energy, special concern: cold-bridges	medium improvement, depending on existing systems; additional insulation necessary in balustrades	high insulation level possible, special concern on cold bridges	relatively high insulation, danger of high temperature in summer	combination of natural ventilation and heat exchangers possible, high saving potential	combination of natural ventilation and heat exchangers common; high saving potential	combination of natural ventilation and heat exchangers possible, draft in shaft supports ventilation, high saving potential
	Sun screen	every system possible	outside recommends, wind loads	blinds in cavity are protected from wind, absorbed heat is ventilated off	in cavity	in cavity	in cavity	in cavity	in cavity
Aesthetics		retrofitting within original grid, possibility for complete new appearance	good relation inside-outside, few changes in building design possible	very little changes	very little changes	completely new appearance, openings not clearly visible	often horizontal emphasis due to ventilation units	different materials and designs possible	combination of box-window and multi-storey-facade; very big impact
Comfort	indoor climate	installation of new HVAC possible; up to date comfort	depends on existing building services and detailing of facade, improvement of thermal comfort	depends on existing building services and detailing of facade, improvement of thermal comfort	good insulation and high thermal comfort	good insulation in winter, in summer risk of excess-heat	very good insulation, sun-screens necessary, risk of over-heating	very good insulation, sun-screens necessary	good insulation in winter, in summer risk of excess-heat
	natural ventilation	depends on climate concept, often operable windows	possible to integrate, not very common	not possible	possible; demands "intelligent user"	high air velocity in cavity	individual possibility of ventilation, heat exchangers	individual possibility of ventilation, heat exchangers	Individually controlled mechanical with heat recovery
	operable windows	common	rare, depends on HVAC concept	not possible	possible; demands "intelligent user", risk of condensation	condensation-risk on outer skin, fire protection, sound transport from other floors; possible	sound transport to other room	common, condensation risk	possible
	influence of user	depends on installed/ renewed HVAC	HVAC not changed	rare	possible	individual controls common	individual controls common	individual controls common	individual controls common
Building services		possible to integrate installations	integration rarely realized, ventilation units possible	central ventilation required, different heating / cooling means possible	existing systems may be re-used, individual systems possible	installations possible if existing facade and system permit	heat exchangers common, heating and cooling possible	heat exchangers common, heating and cooling possible	heating and cooling possible, fresh air through cavity, exhaust via shaft
Combination with installations	central HVAC	O	O	++	+	++	+	O	O
	radiator + climate ceiling + natural ventilation	+	++	O	+	O	O	+	O
	low temperature system	O	+	-	-	O	O	O	O
	Decentralised HVAC	+	++	+	+	O	+	++	++

Figure 3: Table 1 Overview of façade-principles for refurbishment

S1:

The replacement of existing curtain-walls or pre-fabricated facades with a similar façade construction provides the widest range of possibilities. The main focus of detailing lies in the connection to the main bearing structure. Climate- and architectural design can be solved according to actual standards. This way of refurbishment is particularly feasible, when a total renovation is due and the building is emptied. It then is more sustainable than demolishing the entire structure.

S2:

Replacement of existing windows and extra thermal insulation of walls proves to be the most common way of dealing with façade renovation. It is cost effective and sustainable in terms of material consumption. It does usually not take advantage of the possibility to upgrade building services and is mainly applicable for window-facades.

Di:
Application of an additional façade layer from the inside is predominantly interesting for listed buildings. Dependant on the quality of the existing façade it can be realized as exhaust façade (Di1) or box window (Di2). Special tasks in this case lie in the insulation of cold bridges and the integration of existing HVAC.

Do1:
The addition of a second layer to the existing skin prevents interference with the interior. The application of a multi-storey-façade is a relatively cheap solution providing good extra insulation. The curtain wall is connected to the main load bearing structure; the existing building-services are updated. Any double façade bears the typical risks of overheating in summer and fire-protection difficulties. Operable windows support sound transfer in the cavity and the risk of condensation on the outer glass.

Do2 - Do3:
Corridor facades and Box-type facades provide different levels of horizontal and vertical separation of the cavity which keeps the façade controllable. These systems also provide good circumstances for the integration of new building services. Prefabricated elements are attached to the existing structure; horizontal separations can serve for bringing media to every office-space.

Do4:
The integration of all building services into the façade, realized in form of decentralized units, presents maximum flexibility. Existing installations can be kept in place, though set out of use. All new services are provided from the outside. Decentralised units give users the maximum possibilities to adjust indoor climate individually. Difficulties lie in the detailing of connections to and penetration of the existing structure.

One example of an additional façade with decentralized building service installation has been developed in 1999 in co-operation with Delft Technical University. Within the research project the author has been given the opportunity to develop the system further and apply it to a case study.

5 CASE STUDY - REFURBISHMENT WITHOUT INTERFERENCE WITH INTERIOR

The case study building was constructed in 1972 and is composed of a 3 storey base which serves as conference centre and a 10-storey office-tower on top of this base which is the focus of the research (Figure 4). The façade provides various building physical problems such as rainwater entering the construction and lacking wind-tightness. All office-spaces are fully air-conditioned by means of decentralized units. The system is controlled centrally and not adjustable by the user (Figure 5). Actually the building consumes over 1.2 million kWh/a (315 kWh/m²a) of energy, of which round 80% are used for heating and cooling. (Evers et al.).

Figure 4: Outside view

Figure 5: Existing climate-units

Currently the building is used by the owner himself but it is intended to rent out office space in small units in the near future. Keeping this in mind the owner wishes to reduce running costs and give the building a new and modern appearance. A special task in this project lies in the fact that the interior has recently been refurbished. Therefore it is neither affordable nor desired to interfere with finishes.

5.1 *Application of the system*

Based on the given circumstances the application of an extra façade on the outside appeared to be the optimal solution. During the design process, in co-operation with a climate engineer three different designs were developed.

In a “minimal constructional impact solution” (version 1) most of the façade stayed in place. Existing windows and climate-units were replaced and extra insulation added. In the feasibility study this led to extra costs for relocation of staff and renovation of the interior while the maximum positive effect on energy saving could not be reached in simulations. A second option aimed on maximizing the energy savings (version 3). In this design an entire climate skin was installed; solar-chimneys contributed to the support of natural ventilation. This solution prove to be too expensive in comparison with the achievable payback on energy saving and added property value. Furthermore it led to structural complications.

5.2 *Architecture and construction*

The preferred solution (version 2) aims to combine advantages of both others and be in favour of the architecture: A second skin is placed only in front of the existing glazing. Vertical profiles, suspended from a steel-framework which rests on the main bearing structure, give a structure to the building. This creates a vertical emphasis and transparent appearance for the office tower. (Figure 6) The existing closed facade will not be changed (Figure 7). Besides avoiding disturbance with the interior this also contributes to fire protection. Sprinkler installation in both the cavity and near the façade inside office-space avoids the need for horizontal separation of the cavity. All sprinkler-tubing is installed within the additional façade.

Figure 6: Design for refurbishment

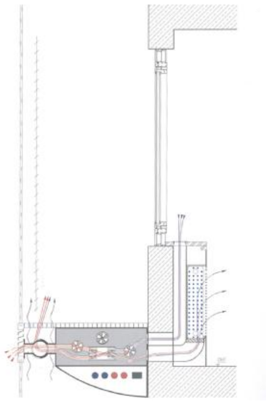

Figure 7: Schematic principle of the facade

5.3 *Climate-Design*

To prevent interference with the interior the covers of the existing climate units are re-used. Modern de-central climate units are installed therein. These units provide individual mechanical ventilation with heat recovery and combine this with convector units for both heating and cooling. In wintertime the preconditioned air from the cavity is used, while exhaust air is let out to the outside. In summertime fresh air is drawn in from outside, while the solar chimney effect in the cavity supports exhaust ventilation. Every room is equipped with controls for individual regulation of ventilation and heating/cooling.

5.4 *Results*

The biggest economic and ecologic gain lies in the improvement of the building performance. Simulations have proven that the proposed solution (version 2) provides an energy saving potential of 75%. The actual 315 kWh/m²a primary energy demand will be reduced to 81 kWh/m²a in the future (Evers et al.). This is mainly based on better insulation and an accurately adjustable HVAC system. Figure 8 also shows that cooling-energy is almost not required; this is due to sufficient sun-screens and ventilation(Evers et al.).

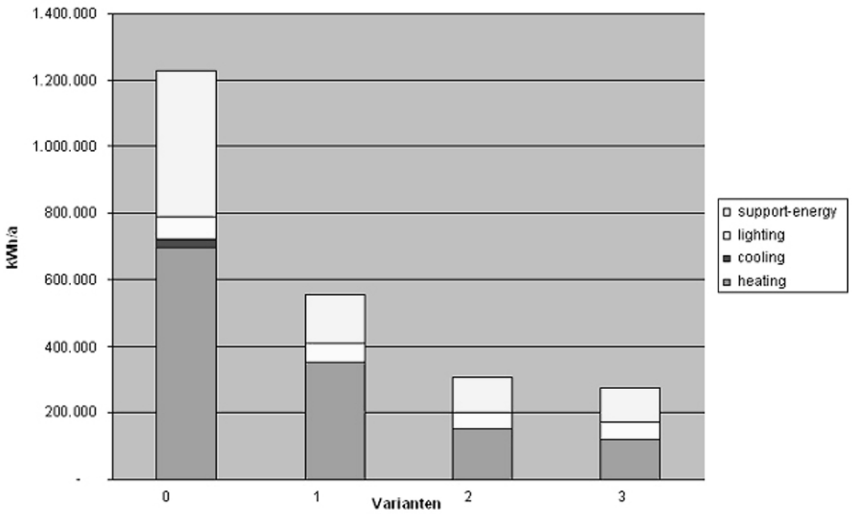

Figure 8: Total final energy consumption (Balck + Partner)

The feasibility study showed that only on energy savings the break even point for the installed building services will be reached within 11 years (figure 9). This is due to the facts that energy costs will rise and that the “old” HVAC-system will require significantly more maintenance. Taking the entire refurbishment-project into account, the investment will pay back only on energy saving within 18 years (figure 10), which is well within the technical lifespan of all its components. (Evers et al. 2006)

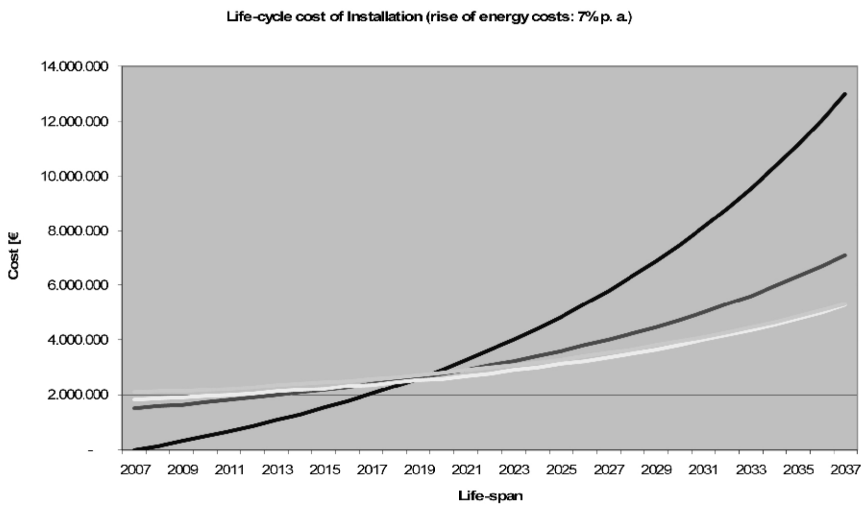

Figure 9: Life Cycle costs HVAC (Balck + Partner)

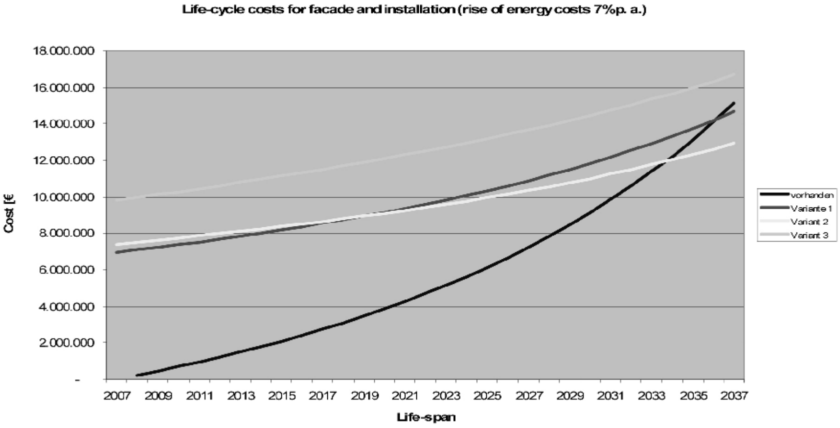

Figure 10: Life Cycle costs project (Balck + Partner)

The feasibility study has not taken into account further added value like better lettability and higher rental rates that can be achieved. One example shall represent these factors: New, smaller, air-conditioning units are placed in the existing. When the interior will be renovated, the big covers will be replaced by smaller ones. This will lead to a gain of 14 m² or 4% of rentable area per floor.

6 CONCLUSION

Facades are one of the most important and complex parts in building. The integration of new materials and climate installation into the building envelope is state of the art and will be one of the major tasks for the future. Façade renovation has to be considered together with climate design. It provides the chance to save material and energy and thus improve sustainability of buildings. The real estate market offers a great number of projects for refurbishment. The author’s research shows that integrated envelopes are applicable in refurbishment projects.

Double skin facades provide a number of disadvantages such as overheating in summer and condensation in winter, high costs and a bigger consumption of resources and grey energy. Nevertheless, for the task of renovation they may be particularly useful, as they provide installation space and the big opportunity to build without interference with on-going work and the interior.

Taking all aspects of renovation into account system-based solutions can be developed for the market. The integration of services into the building envelope provides many advantages particularly in renovation. The big task for planners is to prove that such solutions are economically feasible and individually adaptable. For this it needs more case studies which show that intelligent renovation in Europe not only supports sustainability but also is profitable investment.

7 REFERENCES

Brookes, A. 1998.*Cladding of Buildings*. London: Spon
EU directive 2002/91/EC on energy performance of buildings
Evers, Balck und Partner, TU Delft. 2006. *Feasibility study Sparkasse Ludwigshafen*
Hausladen, G. 2005. *Clima Design*, Munich: Callwey
Herzog, Knippers, Lang. 2004. *Facade manual*. Basel: Birkhaeuser
Krewinkel, H. 1998. *Glass buildings*. Basel: Birkhaeuser
Oesterle, Heussler, Lutz, Lieb. 1999. *Doppelschalige Fassaden*, Munich: Callwey
Poeggeler, B. 2005. *Warum brauchen die Häuser in Europa einen Pass?*. www.europa-digital.de
Pottgiesser, U. 2004. *Fassadenschichtungen Glas*, Berlin: Bauwerk
Russig, V. 1999. *Gebäudebestand in Westeuropa*, Munich: IFO Schnelldienst
Schlomann, B. et al. 2004. *Energieverbrauch der privaten Haushalte und des Sektors GHD*

Characterization of the Lisbon elementary public school building stock

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ABSTRACT: Lisbon elementary public schools serve a population of 15800 children, with ages ranging from six to nine years old. The existing building stock was built, on average, 50 years ago. This is even more worrying because, in many cases, the original buildings have not been submitted to any relevant maintenance practices or renovations. This paper reports the results of the follow-up study that began in 2007 to collect information on the actual condition of these public schools.

1 INTRODUCTION

Lisbon elementary public schools serve a population of 15800 children, with ages ranging from six to nine years old (30% of these children live in the outskirts but the expenses are supported by the City Council of Lisbon - CCL).

The elementary educational school facilities include 97 buildings, most of them property of the municipal authority and a few rented. CCL, as responsible for the activity of facilities management, must deal with a variety of building construction styles and functional concepts such as one school building dated from 1875 or a group of school buildings belonging to the construction program for educational facilities from the period called "Estado Novo" (1926-1974).

The existing building stock was built, on average, 50 years ago. This is even more worrying because, in many cases, the original buildings have not been submitted to any relevant maintenance practices or renovations. Lack of maintenance and conservation speeds up the deterioration of the buildings and the need to replace equipment, it increases the cost of maintaining school facilities and it can also result in health and safety problems.

A study on the physical condition of Lisbon elementary public schools was conducted in 2003 by the CCL. Data was compiled based on the overall condition of various types of the building exteriors, and an identification of the main building features' problems was also performed: roofs, exterior walls, framing, windows, plumbing and electric wiring.

This paper reports the results of the follow-up study begun in 2007 to collect information on the actual condition of these public schools. They provide an outlook of current maintenance practices and contribute to the knowledge of how local authorities manage their schools' facilities.

To maintain and improve the quality and performance of school buildings it is important that local and governmental authorities are aware of the necessity of adopting sustainable maintenance practices for the existing building stock. The implementation of such practices requires an accurate assessment of each type of school building's characteristics. A large number of Lisbon elementary schools are made up of old buildings, with historical and architectural value, and a small number of buildings from the 1980/90s. Current maintenance practices must be implemented immediately as well as a written long-range facilities plan for making major repairs, renovations or replacement of building features.

2 BUILDING MAINTENANCE

The maintenance of buildings may have different natures: deferred, emergency, corrective, general, preventive, predictive and proactive. Figure 1 illustrates the sequence of these seven different types of maintenance in accordance with the level of planning (OLA 2000).

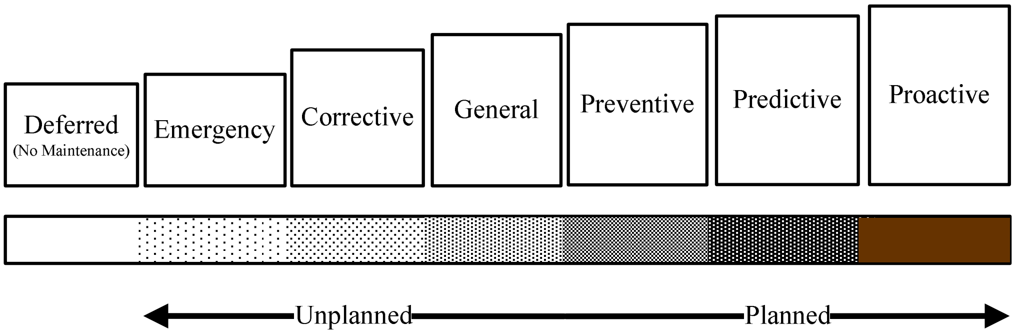

Figure 1. Types of maintenance (Source: Office of the Legislative Auditor 2000)

Maintenance is said to be deferred when identified needs to execute works are not followed through. Budgetary limitations or weather-related factors may be the reasons that motivate this delay (Arditi 1999). Emergency maintenance occurs when there are urgent situations that involve users' health and safety that demand immediate response. Maintenance is corrective when there is a need to repair unimportant elements that, even though are not of an urgent nature, cannot wait for general maintenance. Emergency and corrective maintenance are activated to provide response to situations when failures occur (BRE, 2003).

Maintenance is said to be general when works aim at reestablishing the elements' initial conditions and allow their functioning under good conditions of performance. When there is a serious planning of the activities to be developed, namely inspections, evaluation of a building's condition status and execution of subsequent repair works on the various elements, and a register of all these periodical activities, maintenance is said to be preventive (OLA 2000).

For predictive and proactive maintenance, tests of the elements are used that allow, in the first case, to detect performance trends before failure occurs and, in the second case, to detect the failure's origin. It demands a high level of planning with a restrictive scope (OLA 2000).

Even though it demands an initial and constant investment of technical and financial resources, preventive maintenance allows for the maximization the operational capacity of the facilities, extending the components' service life, preventing the occurrence of unpredicted failures that always lead to costlier repairs, minimizing lost time, avoiding closing down the building, saving energy by keeping the ventilation equipment in a good state and preventing significant degradation of the building's envelope. Its absence leads to an acceleration of the degradation with sometimes irreversible results and extensive increments of the repair costs.

The strategies to be adopted in managing a building stock involve balancing the planned and non-planned maintenance activities.

Factors pointed out as relevant in maintenance management of the building stock are: the age of the buildings and their condition status, characteristics of the construction - architecture, areas, function, installations and equipment - (Arditi 1999) and also the quality of the materials and components used, the criminality rates and aspects related with the building's location (BRE 2003).

3 RESEARCH METHODOLOGY

In terms of data collection, the online databases of the City Council of Lisbon (CCL), the Information and Evaluation Cabinet of the Education System (GIASE) from the Ministry of Education and the Regional Education Direction of Lisbon (DREL) were consulted.

It was possible to collect data concerning the total number of schools, their geographic distribution in the Lisbon parishes, the number of students per school and the total number of students. Data concerning the existence of kindergartens and/or other levels of learning (integrated schools) were also collected even though it was not possible in most cases to understand whether they function in autonomous buildings or in common areas.

The GIASE also provides data on the curricular activities made available by the schools, while the CCL provides the construction date of the building and patrimonial elements (ownership of the buildings) for some schools. By cross-referencing data from these three databases it was possible to check the accuracy of the data presented here even though regularly there were some discrepancies mostly due to schools which had been shut down during the present school year or very recently.

To complement the data collected, some visits were made to the buildings (from the outside) and some informal telephone contacts were established with the management of the schools.

4 FINDINGS AND DISCUSSION

4.1 *General data on the building stock*

Lisbon is divided into 53 parishes and, according to the CCL online, the elementary schools (1st cycle) are located in 43 of them. In figure 2, a map of Lisbon is presented showing the approximate geographical distribution of the elementary schools.

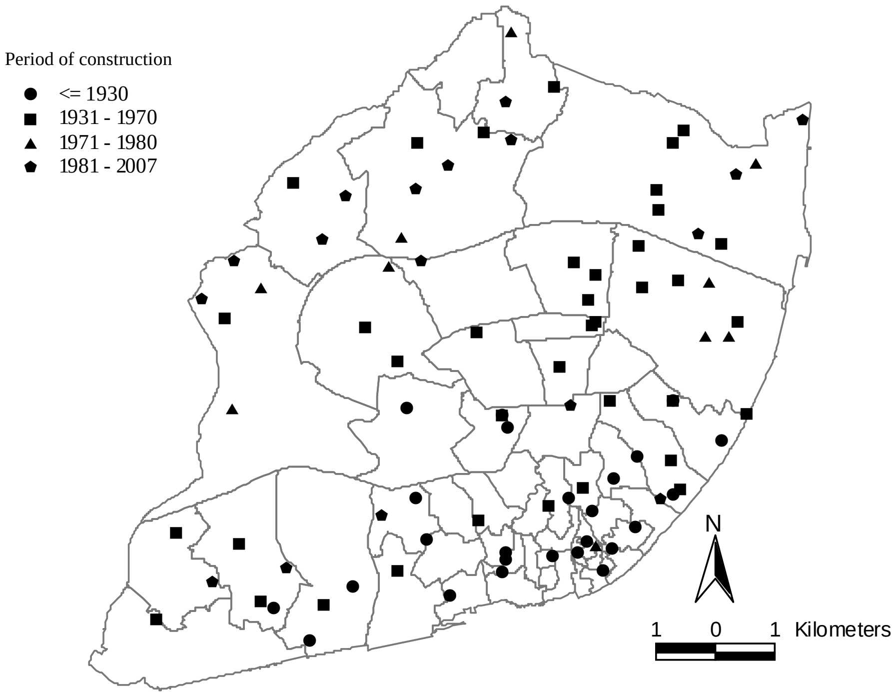

Figure 2. Distribution of the schools by parishes in the city of Lisbon

Table 1 presents a summary of the results relative to the date of construction and the average age of the buildings. The building stock is made up of old buildings, some of them over 200 years old, located mostly in the city's oldest districts that still represent around 24% of the global stock. However, the buildings of the "Centenary Plan", from the 30's to the 70's, of the *Estado Novo* make up the greatest percentage (41%). The most recent schools from the 70's and 80's and after the 80's represent respectively 14 and 21% of the stock.

Table 1. Schools by construction period and average age

Construction epoch	**Buildings**		**Construction date**			**Average age**
	No.	%	Minimum	Maximum.	Average	
Before 1930	22	24	1742	1918	1826	181
From 1931 to 1970	38	41	1932	1970	1954	53
From 1971 to 1980	13	14	1972	1980	1975	32
After 1981	20	21	1981	2002	1988	19

The construction date and the average age per construction period must be considered as a good enough indicator to be used in the first stage of the characterization of the school's building stock. The determination of the actual age of each building will have to take into account the history of maintenance activitiy, improvement and rehabilitation performed throughout the years (NCES 1999).

As referred by Hinum (1999), the quality and longevity of the buildings are affected by the way they are taken care of, maintained and preserved and also by the evolution of the functional requisites demanded by the users (obsolescence).

In figure 3, it can be perceived that there is a greater number of small schools in the older buildings and that the predominant dimension of the schools, defined by the number of students, is in the interval of 125 to 300. In terms of distribution of students by construction period 44% of the 15800 students use schools from the *Estado Novo* period. On the other hand, in 60% of the buildings the pre-school level (kindergarten) is installed either autonomously or not.

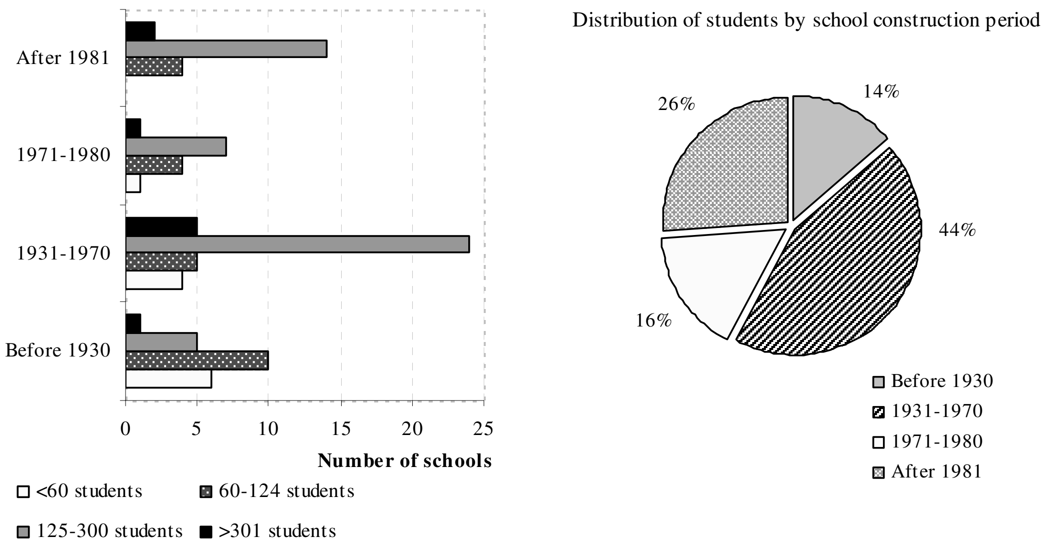

Figure 3. Dimension of the schools and distribution of students by school construction period

4.2 *Data on construction technology*

The building stock is made up of buildings that comprise a wide range of construction periods and therefore present a variety of characteristics both at the architectural level and of the materials and construction solutions.

Until 1930, buildings designed as dwellings and later adapted to be used as schools prevail. Many of them are classified as municipal heritage or located in protected areas, in the oldest Lisbon neighbourhoods, presenting characteristics from the *Pombalino* Period (built after the 1755 earthquake until 1870).

Generically they are 3-storey buildings plus mansard with high ceilings (4 meters) that present a masonry and timber framed vertical structure, and horizontal structure and roofs also in timber. Roofs are slanted and coated with ceramic tiles, outer walls present painted renderings and stone cladding and two-leaved windows are in timber with inner shutters. Inner walls are usually rendered in gypsum plaster, ceilings are made of gypsum plaster on lathing and pavements of timber boards and natural stone (report CCL 2003; Sousa Oliveira & Reis Cabrita 1998). In figure 4 (left), the building where school 13 is installed, in downtown Lisbon, is presented.

From 1930 to 1970, buildings were originally designed as schools and were built within the "Centenary Plan" (Beja, F. et al. 1996). Initially (until the 50's) the structure of these buildings is characterized by pavements in timber girders resting on masonry walls, sometimes with reinforced concrete slabs in the WC and common areas. These facilities are two stories and have two separate areas, for female and male students. Roofs are slanted and coated with ceramic tiles. Inner walls, in hollow brick masonry, are coated with lime and sand renders. Some of the typical pavement claddings of the period are still present, e.g. cement and marble sand plaster and blue limestone (Bernardino 2003). Figure 4 (right) presents the building where school 142 is located.

From the 50's to the 70's, the use of reinforced concrete structures became generalized, using light prefabricated slabs, horizontal roofing with fibrocement sheets or waterproofing as cladding, and double walls in brick masonry. The topping of roofs, namely those with reduced slanting, is made with short vertical slabs and vertical plumbing is embedded in the walls. Original window frames are in timber.

Figure 4. School 13 (left) in downtown Lisbon and school 142 (Actors District) (right).

In the 70's and 80's, schools were built according to the "Standard Project for Elementary Schools" later known as schools type P3. It is a heavy prefabrication design, composed of modular blocks up to two stories high. The standard structural solution was not always used and there are schools with the same modular typology but with a structure of concrete cast *in situ* (Bernardino 2003). In figure 5 (left), school EB1 in Telheiras is presented.

In the early 80's, schools with great areas as part of the plan were built with low budgets in the new town districts, now generally very degraded (Bernardino 2003). Buildings from the end of the 90's and early 2000's seem to offer good conditions, both in terms of construction and functional spaces (figure 5 (right), Alto da Faia school). The Vasco da Gama school located in the Expo 98 area, inaugurated in 1999, incorporated a pioneering experience to be followed in the years ahead of concentrating a kindergarten and every elementary school level (EB1, 2 and 3) in one single building.

Figure 5. Telheiras school (left) Alto da Faia school (right) in Lumiar parish.

4.3 *Data on the overall condition of the buildings*

In 2003, the CCL performed evaluations of thirty buildings of the school building stock aiming at checking and identifying the aspects related with structural safety, service safety and safety against fire (CCL 2003). Due to reasons inherent to the goal of the work, the schools inspected correspond in most cases to buildings prior to 1930 and even in some cases prior to 1755.

The following occurrences are referred in terms of structural anomalies: foundation deficiencies (5 schools), incompatibility of the structure in terms of overload above regulatory levels (13 schools), cracking in vertical bearing elements (15 schools), cracking in horizontal bearing elements (7 schools), timber rot (15 schools), unstable ceiling cladding (15 schools) or brittleness of the structure due to posterior works (7 schools). An analysis concerning the earthquake-related anomalies was performed with reference to walls deformation to unlevel, walls buckling, punching effects in walls and cracking of stone frames of windows and doors.

It was difficult to analyze the overall condition of the oldest buildings, because throughout the years they have been subjected to improvement and rehabilitation works in which materials and claddings typical of the periods when the works were performed were used.

Of the 30 schools inspected, around 20% presented roofing cladding materials of more than one type, ceramic tiles being the most frequent of them (present in 80% of the buildings). In 2003, the need to replace fibrocement in 23% of the schools was referred to since they were falling behind code regulations. In 59% of the cases, roofing claddings were classified in good condition, 33% in reasonable condition and 8% in bad condition. Pavement claddings were classified in reasonable condition in 63% of the cases, in 27% as good and in 10% as bad. In 47% of the cases, classroom ceiling claddings were in reasonable condition, in 30% in bad condition and in 23% in good condition. Water plumbing was classified in reasonable condition in 87% of the cases and sewer plumbing in 68%.

The report proposes the shutting down of some schools (that have been closing), sometimes because they do not present good working conditions or safety in the case of an earthquake, for safety reasons or related to patrimonial and financial management of resources.

In 2006, with the elaboration of the Lisbon Educational Chart, an evaluation of the conditions of the learning establishments under the cargo of the CCL was performed. Some of the little data available point to the need of performing great repairs in 53 of the 96 schools focusing on roofings, facades, ceilings, walls and pavements, water and sewer plumbing, electric and gas systems and also sanitary and kitchen equipments (DN, 2006). In the study, three schools were classified in critical situation (one has already been closed, in S. Vicente parish).

5 STRATEGIES FOR THE FUTURE

5.1 *Further data collection and integrated and participated management*

As referred by Freire da Silva and Melo da Silva (2005), characterizing and knowing well the building stock is essential for its management. In 1997, the results of the condition evaluations of the school building stock of the 2nd and 3rd cycle were published and became paramount in the characterization not only of the quality of the facilities but also of the quality of the teaching. The age of the buildings, their type, the school population, the type of construction and the way the space was used were some of the data collected in that study.

In England in the late 90's, an integrated system of analysis and evaluation of school buildings was created, with the following 6 steps: identify responsibilities and attributions of the various parties involved and define objectives and strategies (1); perform the evaluation of the functioning facilities within the net by resorting to the database and compiling all the data on each building (2); identify the needs (3); identify priorities (4); perform viability studies, the validation of options and financial alternatives (5); and execute the works, by implementing rationalized and innovative maintenance (6). The whole system is periodically evaluated (Beeton 1999).

Other countries report progress in various work fronts, e.g. Mexico that in 2006 initiated the use of a computer program of evaluation of school facilities made online. The new system, developed within the 01-06 National Education Plan, was conceived to compile data gathered consistently allowing the reduction of paper and human resources consumption (OECD n.d.).

In Canada, Quebec has developed a school facilities evaluation system based on criteria such as the adequacy of the schools to the new teaching techniques, their adaptation to new environmental requisites and demographic previsions. The method is founded on data "modules" such as component inventory, maintenance impact calculation, execution of financial projections for long-term improvement works, rating of activities by priority, preventive maintenance, repair costs, and the elaboration of a final report (PEB 2005).

5.2 *Adoption of a preventive maintenance*

Planned maintenance actions of a preventive nature should be adopted, requiring task planning for each building. At an initial stage of implementation of the method, it will be necessary to "waste some time" in planning the better way of performing an inventory and codification of the elements that constitute each building (Kishk et al. 2003) and defining the evaluation method of the building state of conservation (Paiva et al. 2006, NCES 2000). This method should bear in mind aspects of standardization in data collection, the teaching of the personnel working on site, and the evaluation criteria of the condition of the different inspected elements. Only by adopting standard procedures and eliminating (as much as possible) subjective judgments will it be possible to compare data from different inspections and dates.

The scope for each inspection (the building as a whole or parts of it) must be defined, as well as the instrumentation needed, checklists and rating and register criteria. The frequency of inspection will depend a lot on the age and state of conservation of the building.

Auxiliary documentation, such as repair files, may be developed gradually, from the most frequent technical solutions within the building stock to the more specific and rare, and by adapting some already developed models (Abrantes et al. 1999, Hoffmann Arch. 1997).

At the stage of establishing priorities and making decisions, aspects that lead to risk of users safety or health (justifying shutting down the school) or, at another level, degradation that jeopardize comfort and salubrious demands are usually considered of maximum priority and urgency.

5.3 *Adoption of tools based on the life cycle analysis of components*

One of the tools to be used is called Whole Life Costing (WLC) and it consists generically in quantifying every cost and benefit associated to the acquisition, use, maintenance and exploitation of any goods. This tool has been essentially used at the design and project stages, in the analysis of alternative solutions, taking into account not only the initial costs but also those resulting from the exploitation and maintenance stages.

Recent studies revealed that around 80 to 90% of the exploitation, maintenance and repair costs of a building are defined at the Project stage (Kishk et al. 2003).

WLF must be used as a support tool in preventive maintenance activity. This analysis, performed by the manager, may reveal that some replacement solutions or the acquisition of a given equipment are more economic in the long run than others.

Some of the obstacles to the current use of WLF result from the time consumed in this type of analyses and, on the other hand and to an even greater extent, the lack of available data on maintenance costs and expected service life of various components. In England there are some manuals, such as those published by the *Housing Association Property Mutual* (HAPM) and the *Building Maintenance Information* (BMI) that provide data on the components' service life and on repair and maintenance costs (BRE 2003). In Portugal there are some publications, such as those from the Institute for Management and Sale of the State Dwelling Patrimony and from the Porto University Engineering Faculty (Abrantes et al. 1999), but they have only a limited scope and need further development and periodic updating. The history of registers of maintenance and repair expenses or the consultation of suppliers are other sources of data to be used.

6 CONCLUSIONS

Various factors that allow the characterization of the elementary school (1st cycle) building stock of the city of Lisbon were drawn.

It was found that there are a large percentage of schools installed in very old buildings in the most ancient districts of Lisbon. These buildings have a great historical and architectonic value but show functional problems and also in terms of the state of conservation. The percentage of students of these schools is low (around 14%) possibly made up of grandchildren of the inhabitants of these old districts that present worrying ageing and desertification ratios. A desirable revitalization of these areas depends on the creation of infrastructures and social facilities that offer adequate conditions to the settling of young families.

The greatest part of the school population attends the schools built during the *Estado Novo* period. These buildings have an architectonic and historical value and even though rather old (from 30 to 70 years) seem to provide functioning conditions and very reasonable performance. The greatest problems are related with roofings, windows, and water and sewer plumbing due to the end of the expected service life of these elements.

The state of conservation of the schools built between the 70's and the 80's is more worrying since apparently the low initial budgets of construction associated with missing preventive maintenance practices are reflected in an acceleration of the predicted degradation ratio of the buildings. Nevertheless, it will matter in future studies to know in detail the deterioration level of the buildings at the technological, functional and economic level.

For more recent schools, built after the 80's, a study of their state of conservation and the implementation of planned maintenance practices have been recommended.

For the future, it is recommended that more data is collected involving all the interested parties, namely users, managers, authorities and the community in general, the adoption of planned and preventive maintenance and also of tools of analysis of the life cycle such as WLC.

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REFERENCES

Abrantes, V. & et. al 1999. Reabilitação de edifícios. Estudo do comportamento e análise técnico-económica das soluções utilizadas nas obras de construção e reabilitação. Porto: IGAPHE.

Beeton, K. 1999. Modernizing the schools infrastructure in England. UEF/PEB/CE International Symposium. Baltimore, USA.

Beja, F. & et. al. 1996. Muitos anos de escolas. Edifícios para o ensino infantil e primário até 1940 (Vol 1) e dos anos 40 aos anos 70 (Vol. 2). Lisboa: Ministério da Educação. Departamento de Gestão de Recursos Educativos.

Bernardino, P. 2003. Thermo-hygrometric rehabilitation of buildings. Application to Lisbon city primary schools. Lisbon: IST.

BRE Construction Division 2003. Estimation of the need to spend on maintenance and management in the Local Authority housing stock. London: BRE Construction Division. Office of Deputy Prime Minister.

Diário de Notícias (DN) 2006. Mais de metade das escolas básicas de Lisboa pedem grandes reparações. http://dn.sapo.pt/2006/11/22/cidades/mais_metade_escolas_basicas_lisboa.p.html

Direcção Regional de Educação de Lisboa e Vale do Tejo (DREL). http://www.drel.min-edu.pt/

Gabinete de Informação e Avaliação do Sistema Educativo (GIASE) 2006. Recenseamento escolar. Dados globais 2006/2007. Lisboa: Giase. http://www.giase.min-edu.pt/

Hinum, M. 1999. Strategies for managing educational facilities infrastructure. UEF/PEB/CAE International Symposium. Baltimore, USA.

Hoffmann Architects 1997. Exterior building maintenance manual. New York City school buildings. NY: Hoffmann Architects.

Kishk, M. & et. al. 2003. Whole life costing in construction. A state of the art review. www.rics-foundation.org

City County of Lisbon (CCL). http://www.cm-lisboa.pt/ e http://lisboainteractiva.cm-lisboa.pt/

National Center for Education Statistics (NCES) 2000. Condition of America's public school facilities: 1999. Washington: NCES. U.S. Department of Education (http://nces.ed.gov).

Office of the Legislative Auditor (OLA) 2000. Preventive maintenance for local government buildings. A best practices review. State of Minnesota. http://www.auditor.leg.state.mn.us/ped2000/pe006.htm

Paiva, J. & et al. 2006. Proposal for an evaluation method of buildings' maintenance state. Report 185/2006 DED/NAU. Lisbon: LNEC.

PEB Exchange 2005. An asset management system for school buildings in Quebec. The Journal of the OECD Program on Educational Building. Vol. 2/2005. No. 55 June.

Silva, J. & Silva, R. 2005. Working to improve quality in educational building: examples and perspectives from Portugal. In Evaluating Quality in Educational Facilities. OECD.

Sousa Oliveira, C. & Reis Cabrita, A. 1985. Tipificação do parque habitacional. Documento introdutório do tema. 1º Encontro sobre Conservação e Reabilitação de Edifícios de Habitação". Lisboa: LNEC.

Overcoming the barriers to improving the sustainability of existing commercial office buildings

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ABSTRACT: There is a perception that a high proportion of the commercial office buildings that we will use this century are already built, that many of these buildings perform poorly with respect to the environment, resource use and user well-being and that while building owners are prepared to spend significant amount of money on cosmetic upgrading, they are reluctant to commit funding to sustainability related performance improvements in upgrades of existing commercial buildings.

Through an analysis of a series of stakeholder interviews this paper seeks to better understand whether or not these perceptions concerning building performance and owner attitudes are widespread. It also seeks to identify the perceived barriers to Environmentally Sustainable Design (ESD) upgrading of existing office buildings and discusses possible solutions to overcome such barriers.

1 INTRODUCTION

A substantial amount about what we 'know' about the sustainability and potential use of our existing office buildings in New Zealand is a combination of, industry experience, anecdotal evidence and conventional wisdom. Collectively this body of knowledge drives the decisions made concerning the development of and investment in existing buildings. It is necessary that these perceptions and attitudes are understood if 'green' agendas are to be progressed.

In this survey a series of key property industry stakeholders operating in Wellington were interviewed. They were asked to consider and respond to a series of statements concerning property sector attitudes and perceptions and to indicate barriers and possible solutions to ESD upgrading of existing office buildings.

The study was focused on existing office buildings in the Central Business District (CBD) of Wellington, New Zealand. Wellington was selected because it is a compact city yet contains buildings having a wide range of physical and performance characteristics in terms of form, size, age, materials, ownership and quality.

Wellington is New Zealand's capital city and about 60% of large lettings of office space are occupied by government departments, quasi government agencies and state owned companies. Government policy is that departments and agencies lease space rather own their own buildings.

Because of a major stockmarket crash and coincidental governmental reorganisation and downsizing, there was suddenly a glut of office space in 1989 and very little new office space has been built in Wellington in the subsequent 15 years. Virtually all office related building work during that period was upgrading existing buildings. During this period a significant number of existing office buildings were adapted for use as apartment buildings. A high proportion of existing office buildings in Wellington were built in the 1960s, 70s and 80s, fuelled by high demand and the identification and replacement of earthquake hazard buildings.

Many of the buildings built at this time were built on a speculative basis by developers who sold them on as quickly as possible. They were often constructed to the lowest possible cost and specification.

The current ownership pattern is for buildings to be retained and leased out by their developers. In the last two years several major new office developments have been started. Several of these buildings have been designed to achieve a 4-5 Greenstar NZ rating, equivalent to Silver and Gold ratings under the LEED assessment system. These developments are likely to have a significant effect on the commercial viability of existing office buildings in Wellington.

Comments of one of the respondents were made on the basis of a series of 20 industry workshops organised by the respondent to discuss the future of Wellington's CBD (Dow), but in all the other cases respondents cited industry knowledge and experience rather than evidence based research as their information source.

2 EXISTING OR NEW

Industry professions were asked to respond to the statement *"A high proportion of the office buildings that we will use this century are already built."*

There was significant variation in the responses obtained ranging from full agreement to disagreement. The developer-owners (McGuinness, Burrell) suggested that in the immediate future new, waterfront buildings with large footprints are favoured and that while existing buildings are being renovated this can often involve a total rebuilt behind a retained façade and in some cases this was also accompanied by a change of use.

Others respondents suggested that most existing buildings were likely to be retained and upgraded in less drastic ways (Humphries, Myers)). Some upgrading is occurring on a floor by floor, piecemeal basis using simple, usually energy related technologies, such as heat pumps, new generation fluorescent lamps and better control mechanisms (Humphries). It was suggested that rainwater collection would be comparatively simple to install and could result in major water savings (Baker). Humphries suggested that it was uneconomic, impractical and logistically impossible to perpetually renew all our existing office stock.

In the longer term it was suggested that the workplace environment was likely to undergo radical change and that this would significantly impact on the nature and composition of the CBD (Dow, McGuinness). One particularly compelling CBD scenario suggested that only small 'shopfront' workplaces combined with a mixture of, common, amenity, residential and retail spaces would be located in the CBD with other workplaces being remotely located. This vision would, it was considered, lend itself to the reuse of smaller footprint characteristics of good quality, older, existing buildings (Dow).

Several respondents considered that buildings built during the 1960s, 70s and 80s would be economically difficult to change for continued office use and that that these same buildings were most at risk of demolition or of being stripped back to their basic structure prior to rebuilding. Buildings with a good 'image' were thought most likely to be retained and refurbished and were likely to include significant 'green' features in their upgrading.

Replacement rates information is not readily available in New Zealand, but the consensus view was that the replacement rate for office buildings is around 1.5% per annum. This suggests an average 50-60 year replacement cycle

A study by The Athena Institute in 2003 into the reasons for demolition of buildings in St Paul, Minnesota, USA, concluded that while a major (22%) reason for demolition was that the building was not suitable for its intended purpose, the cost of improvements required to bring the building up to Code requirements accounted for a only a tiny fraction (2%) of the numbers of demolished buildings involved (The Athena Institute). The results of this survey cannot be directly transferred to Wellington, New Zealand, but suggest that if alternative uses can be found for buildings found to be unsuitable their original purpose, then the cost of bringing the building them up to Code would probably not inhibit conversion.

3 PERFORMANCE OF EXISTING BUILDINGS

Stakeholders were asked to respond to the statement *"Many existing office buildings perform poorly with respect to the environment, resource use (energy, water and materials) and user well-being."*

Both new and existing buildings will need to have a 4-5 Greenstar NZ rating to attract future government leases. Early indications are that building owners are increasingly interested in what measures need to be put in place to achieve the various Greenstar ratings (Wood).

Several respondents suggested that most corporate tenants are not yet particularly interested in ESD. Existing high occupancy rates suggest that it is still possible to rent out resource inefficient buildings in Wellington. Realtor respondents suggested that ESD features were currently well behind factors such as location and image in terms of the priorities assigned by many corporate entities for spaces they would wish to rent.

Most respondents considered that older buildings performed poorly in terms of operational resource use, but some considered that a combination of operable windows, small floorplates and good natural daylight provided more enjoyable and healthier working conditions for users than many newer mechanically ventilated, overglazed and artificially lit buildings.

Research carried out by the IEA and EC in the BRITA in PuBs extension to Annex 36 concludes that post 1980 buildings comprise 20% of the building stock in Europe but only use 5% of the energy consumption (Erhorn-Klunnig). This research relates to all buildings rather than being specifically related to office buildings, but it tends to support the suggestion that older office buildings are considerably less energy efficient than more modern buildings.

Water use in existing office buildings in New Zealand has not been considered until very recently, because Wellington does not currently have a water supply problem. The new NZ Building Code is likely to mandate water conservation measures nationwide. Government tenants and several publicly funded organisations are beginning to take water conservation seriously with Government pre-empting regulation and insisted that water saving features are incorporated in all its own future leased space.

Generally the measures incorporated are low level, spray taps, dual-flush toilets and low water use appliances but rainwater collection has been incorporated in some recent government leases. The Department of Conservation (DOC) building in Wellington also incorporates rainwater collection, and 65,000 litre storage tanks used for all non-potable purposes in the building. This results in a saving 77% of mains water supply (Baker).

Material conservation is not currently being considered by the property sector although this too will change with the introduction of the new NZ building Code and the application of the Greenstar rating system.

4 APPEARANCE VERSUS PERFORMANCE

Responses were sought to the statement *"Building developers/owners are prepared to spend substantial amounts of money on upgrading the appearance of existing buildings, but very little on upgrading the sustainability related performance of those same buildings"*

The consensus was that until quite recently appearance was more important than performance to most tenants and that in consequence owners tended to carry out mainly cosmetic upgrading of their buildings. This appears to be changing, particularly within the Government sector where 'green' performance criteria now tend to dominate the list of priorities. This trend is seen to be gathering momentum because of actual or impending government regulation and leasing strategies. Respondents suggested that the corporate market as a whole is still not entirely convinced about the merits and value of incorporating sustainable design features in their rentals particularly if it means a rental premium has to be paid. Priorities for many corporate clients remain location, view, image and so visible appearance related improvement still rates higher on their list of priorities than operational performance criteria; but even here the situation is beginning to change.

All respondents agreed that big renters, defined in Wellington terms as those letting more than 3000m2, are now becoming more demanding and more are willing to pay a premium for 'green' features, whereas ten years ago no tenant even mentioned ESD. Even three years ago when the Department of Conservation sought expressions of interest on the basis of a 'green' brief only two out of twelve bidders were willing to offer anything other than a conventional building solution (Baker).

5 OVERCOMING THE BARRIERS

5.1 *Introduction*

Two questions were asked was *"What do you consider to be the barriers to incorporating sustainability related performance improvements into existing office buildings?"* and *"What do you believe would be the best way of overcoming these barriers"*

Twenty one specific barriers were identified. For the sake of clarity these have been divided into four categories, knowledge/education, information/standards/tools, leasing arrangements, cost/value/investment. Identification of the barriers and suggests on how such barriers might be overcome have been brought together in this section of the paper to minimise repetition.

5.2 *Knowledge/education*

1: There is a lack of educational opportunities for decision makes to learn about the opportunities and benefits of 'green' buildings in their own 'language'

Senior decision makers are often unwilling to expose their ignorance by attending open workshops or consulting junior staff and they often do know what they don't know.

Distance education, workshops and seminars for senior managers, open websites, one-on-one teaching, confidential telephone or e-mail consultation provision can all help to overcome this problem.

2: Risks involved in investing in 'green' building upgrades are perceived as being too great, especially by those who have no experience in this area

60% of the big tenants and a significant proportion of the small tenants are in the public sector. With the Government deciding that as from the 1st July 2007 all new direct public service departments office lettings will be in 4-5 Greenstar rated buildings and the likelihood that many other publicly funded organisations will follow suit, there seems to be more risk in not investing in 'green' building upgrades than in doing so.

The new NZ Building Code will define minimum ESD requirements, will reduce the risk factors involved in 'green' renovation yet further and facilitate the transition of 'green' building from an exceptional into a normal way of refurbishing or reconstructing buildings.

Demand for 'green' space is rising and if it is not provided by Wellington based companies it will be provided by Australian property investors, who are more aware of the potential profits to be made, than many New Zealand investors seem to be at this time (Wood).

3: Sub-sector professionals in the property/building industry do not understand the language, imperatives and motivations of people in other sectors of the industry.

ESD aims to provide holistic financially, socially and environmentally sustainable and responsible outcomes and these need to be very clearly communicated to all stakeholders. Opportunities need to be deliberately created through multidisciplinary conferences, events and gatherings to enable these different points of view to be aired, understood and accommodated.

5.3 *Information/standards/tools*

4: E*ven big tenants only have an opportunity to exert pressure on the landlord to provide 'green' features during lease negotiations. Small tenants cannot exert pressure at all.*

The new NZ Building Code will set a 'level playing field' minimum condition for ESD that will apply to all new buildings, to existing buildings undergoing major renovation and to the parts of a building undergoing renovation.

The New Zealand Green Building Council Green Star v1 Commercial Building Assessment Tool is seen as the principle mechanism for voluntary action, just as LEED has been in North America. A preliminary version of the Green Star tool was released in New Zealand in 2006 and a developed version of this tool is due later in 2007.

Taken together these interventions should go part way towards answering this problem. However, tenants whether singly or in groups will still have maximum opportunity to obtain higher levels of 'green' features during lease negotiations. Even small tenants have the option of relocating into a 'green' building and carrying green features into their fitouts.

An international survey carried out by the OECD in 2003 failed to find any mandatory or voluntary regulations anywhere in the world that dealt specifically with 'greening' existing commercial office buildings (OECD).

5: There is a lack of benchmarking tools or industry rating tools for existing buildings.

Myers suggested that an existing office building tool was needed that focused on what was achievable and financially viable and a further tool was required to measure and monitor both new and existing buildings on the same basis. Dow suggested the need for a tool to measure and recognise incremental ESD gains achieved in existing buildings which are not covered by the Greenstar assessment system.

There is a lack of good examples of 'green' renovation in Wellington.

This is still generally correct, but now there is one excellent exemplar of 'green' renovation of an existing building in Wellington. This is the recently completed Department of Conservation (DOC) Headquarters. It has been extensively published and rather to DOCs surprise has generated enormous interest right across the building sector. Its 5 star equivalent Greenstar rating confirms its standing as the new benchmark of economically viable green workplace renovation in New Zealand.

7: Scepticism continues about whether designed performance will be achieved in practice.

There remains a certain amount of truth in this statement, mainly due to the unhelpful, over optimistic predictions and the failure to adequately take account of occupant use factors by inexperienced professionals.

The DOC headquarters building is being extensively monitored and will be able to provide valuable data comparing actual against theoretical design performance. Productivity and satisfaction surveys are also being conducted (Baker). Early indications are that actual performance equal or exceed design performance; for instance energy savings predicted at 40% are actually about 53% (Baker).

Some work has been done in this area by the IEA/EU through Annex 36 (Erhorn–Klunnig) but this is restricted to energy assessment, is not specifically focused on office buildings and primarily uses north European data so its usefulness in the NZ context is limited.

5.4 *Leasing arrangement*

8: 'Green' attributes are only necessary if seeking government leases.

Twelve months ago this statement was essentially correct, however while Government retains its leadership role, other quasi government agencies, state owned commercial companies, local government and state funded organisations such as universities are beginning to follow the Central Government lead. It is reported that a major privately owned bank is seeking to relocate into a 4-5 Green Star rated building. Others are likely to follow.

9: Most buildings in Wellington are multi-tenanted. In this situation leases terminate at different times and landlords find it problematic to carry out whole building upgrades or even piecemeal upgrades especially when remaining tenants have 'freedom from disruption' provisions their leases.

Multi-letting does not prevent tenants adding 'green' features during fit-out work, especially in a 'shell and core' arrangement. Smaller governmental departments and allied organisations are being encouraged to get together and develop a joint 'green' specification so that whole buildings can be let on a 'green' lease basis. This is viewed as a model for groups of small commercial tenants to cooperate to achieve the same end (Wood).

10: Buildings can be readily let without 'green' credentials, so why bother?

One developer–owner considers that a 'tipping point' has been reached in Wellington during the past twelve months and that demand for 'green' space will rise (McGuinness). International experience suggests that lettable space that can demonstrate 'green' credentials is likely to command premium rental rates.

11: A lot of small lettings are for outpost offices of international companies. Decisions concerning performance criteria are often made at head office, remote from the Wellington context.

Internationally an increasing number of companies are going 'green', both to enhance their image and because it makes good business sense. It is likely that these companies will want to demonstrate their 'green' credentials worldwide.

12: Very few small renters research space requirements; they tend to accept what the market has to offer.

While this is perceived to be true, the reason for this remains a matter of conjecture. It may simply be that small organisations feel powerless in this situation. Getting together with other like minded small tenants could alter the situation in favour of tenants.

13: Renters want new not refurbished existing buildings.

The current demand is for new, buildings located on the waterfront in Wellington. However such locations are at a premium. It is likely that demand will quickly outstrip supply. One commentator considered that as more organisations move more towards evaluating the cost to 'service' each employee, finding a good match between identified needs and renting the minimum space to satisfy that need, would become the priority concern for most organisations (Dow).

5.5 *Cost/value/investment*

14: There is a lack of knowledge about the real costs and benefits of 'green' renovation by tenants, landlords, owners, valuers and realtors.

The new generation of designers, engineers, investors, building owners and accountants are likely to emerge from their training with greater knowledge of green issues, challenges and opportunities. However their training must include broad based education on and knowledge about the interactions required to maximise benefit for all parties involved.

15: There is often no recognition of any extra value of 'green' features in rent reviews or in property owners building classification systems so landlords are unwilling to go to the extra expense of incorporating 'green' *features.*

Green leases seek to address this dilemma. With green leases the 'green' component is explicitly and separately acknowledged and factored in as extra rental to avoid its becoming lost during rent review negotiations. 'Flexible' leasing is another method of addressing this situation. With a 'flexible' lease arrangement a tenant commits to rent space from a particular owner for an extended period but the actual space occupied can change depending on organisational circumstances. The landlord has the security of knowing that they will make money from the tenant for a long period and can afford to satisfy particular 'green' requests at the beginning of the lease period, while the tenant knows that they do not have to remain in a space that no longer suits their needs.

16: Very few 'green' buildings are available in Wellington.

In the rapidly changing sustainable design sector and with the current high levels of space take up in Wellington this is probably inevitable. With Government and other publicly owned or financed organisations accounting for 60% plus take up of lettable space in Wellington, demand will almost certainly grow. Achieving a satisfactory balance between supply and demand may take some time. In the meanwhile 'green' buildings are likely to command a rental premium. The original developer-owner of the DOC building has indicated that in today's market they would have been able to achieve an additional 30% rental premium if he were letting this building today.

17: Lack of experience and expertise by professionals may lead to excessive on-costs.

The US experience is that as professional expertise grows 'green' building on-costs fall. In many cases the greatest benefits seem to occur when the same team works together on a series of contracts (Kats).

18: Owners-developers still focus on initial rather than life cycle costs.

Tenants are now much more demanding and, as most new and refurbished schemes are pre-let before work starts on site, tenant requirements for 'green' enhancements can be accommodated if the tenants are willing to pay for the ESD performance enhancements requested. Some measure of longer term thinking is however required by all of the parties involved and such thinking is beginning to emerge.

19: Refurbishment of buildings to incorporate 'green' design features is costly and tenants are unwilling to pay for ESD upgrades.

In the Wellington situation at least the cost of not going 'green' in terms of lost opportunities, rental premiums foregone and in the self-imposed limitations on the types of tenants the building will attract is more significant than the cost of going 'green'. There will always be tenants who want to pay as little as possible and resist change but these are increasingly likely to be the companies at the low end of the market.

While some developers consider that the initial on-cost of 'green' refurbishment is likely to be in the order of 25% over the cost of conventional refurbishment, the DOC headquarters conversion demonstrates what can be achieved on a more modest budget. In the DOC HQ, landlord capital on-costs were about 12% and tenant capital on-costs about 10% to achieve this building's 5 star Green Star NZ equivalent rating. All investments will achieve payback well within the guaranteed lease period.

Kats (2003) suggests that in California the capital on-cost of building 'green' in new and refurbished buildings is quite low and reduces over time, with many 'green' buildings being built/refurbished within the same cost budget as a 'conventional' building. On average the on-cost to achieve LEED Silver and Gold standard buildings, equivalent to Green Star NZ 4 and 5 star ratings in California, was 2.11% and 1.82% respectively, having reducing from 3-4% over a period of years, as professionals became more familiar with techniques and technologies and as green material costs reduced. In New Zealand these on-costs are currently more in the range of 2-6% (Fulbrook), but are likely to fall over time in the same way and for the same reasons as have done in the USA.

20: There are no subsidies or incentives from Government to go 'green'.

Some countries have incentive and subsidy schemes in operation to encourage take up of particular technologies or to encourage changes in user behaviour, but successive New Zealand governments have resisted going down this path. Instead the NZ Government has chosen to use its considerable purchasing power to induce market change. To this end it is 'greening' its leasing arrangements, is currently considering the level of ESD to be employed in directly owned buildings, is operating a preferential 'green' purchasing policy, and is providing strong support for 'green' legislation in the building sector.

21: It is very difficult and costly to upgrade existing buildings to the same performance levels as new buildings. Yet if there is not to be two tier market existing and new must compete on equal terms.

The refurbishment work carried out for the Department of Conservation seems to indicate that this perception is not necessarily correct but most respondents agreed that buildings built prior to 1960 are often easier and less costly to renovate than those built between 1960 and 1989, many of which were built to minimal standards of constructional quality and space.

CONCLUSIONS

There has been a massive positive shift in attitudes to the provision of 'green' space in Wellington during the last twelve months. This has been driven both by the firming up of government commitment to the 'greening' of the public sector and because several 'green' building exemplars can now be visited. There was a perception that the CBD area would change significantly over the medium term with a need for more multi-functional buildings that are much more adaptable than the current generation of multiple-use buildings.

There was general agreement that buildings built during the 1960s, 70s and 80s are just as resource inefficient but are less well constructed harder to adapt and provide a poorer quality of user well-being than earlier buildings, that professional organisations tend to be slow to respond to 'greening' buildings and that many commercial companies are still not fully convinced of the merits and benefits of 'green' upgrading.

There is considerable discrepancy between various respondents concerning the on-costs of 'green' renovation of existing office buildings. This is a very significant barrier and merits further investigation.

One of the next steps in the research process is to prepare a list of direct questions based on the responses received to date and direct them through a postal questionnaire to a full range of industry professionals in numbers sufficient to produce statistically meaningful results concerning the topics raised.

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REFERENCES

Baker, G. 2007. *Personal communication*, Wellington, New Zealand.
Burrell, R. 2007. *Personal communication*, Wellington, New Zealand.
Dow, P. 2007. *Personal Communication*, Wellington, New Zealand.
Erhorn-Kluttig, H. Erhorn, H. and Wossner, S. *Exemplary retrofit Concepts in Europe: Energy efficient public buildings; Proc. Nordic Building Physics Symposium, 2005*. Reykjavik, Iceland
Fulbrook, D. Jackson, Q. & Finlay, G. 2006. *The value case for sustainable buildings in New Zealand*, Report for Ministry for the Environment, Wellington, New Zealand.
Humphries, P. 2007. *Personal communication*, Wellington, New Zealand.
Kats, G. et al 2003. *The Costs and Financial Benefits of Green Buildings*. A Report to California's Sustainable Building Task Force, San Francisco, California.
McGuinness, M. 2007. *Personal communication*, Wellington, New Zealand.
Myers G, 2007. Personal Communication, Wellington, New Zealand.
O'Connor, J.. *Survey on actual service lives for North American buildings; Proc. Woodframe Housing Durability and Disaster Issues Conference*, Forest Products Society 2004. Las Vegas, USA
OECD 2003. Environmentally Sustainable Buildings: Challenges and Policies, OECD Paris, France.
The Athena Institute (2004) Minnesota demolition survey, phase 2 report, Vancouver, Canada.
Wood, C. 2007. *Personal communication*, Wellington, New Zealand.

Sustainable management of existing building stock: a strategy to reduce the energy consumption and the environmental impact.

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ABSTRACT: People aim for quick efficiency results, once they have decided to modify building behavior. Technical University of Catalonia (UPC) has drawn up a Sustainable Development Plan (CITIES, 2005) which aims to join efforts within education, research, operations and management activities over the 2005-2015 period. UPCO2 program has been created to reduce greenhouse gas (GHG) emissions at UPC. Buildings of the UPC have already been the subject of several studies, including a PhD Thesis (LOPEZ PLAZAS, 2006) which identified that, for the main energy appliance (heating, ventilation and air conditioning: HVAC), the final energy consumption in this type of buildings, depends on three fundamental parameters: energy demand, efficiency of systems and management. Results of this Thesis showed that the influence of management and use on energy consumption reached 22 to 38% for the UPC buildings studied, and that management conditioned the rest of parameters. The Higher School of Architecture (ETSAV) building, near Barcelona obtained the worst results and was chosen for a detailed study, which consists in translating the results and conclusions of the PhD work to the ETSAV building at first, then establishing a regular analysis and management procedure for the energy consumption, and finally becoming a reference for the sustainable planning of the university.

1 SCOPE

The objective of this work is to identify the possibilities to optimize the use and management profile of the ETSAV building, as part of a strategy to reduce carbon dioxide emissions associated to the energy resources consumption as quickly as possible.

2 CONTEXT: ENERGY CONSUMPTION AND CARBON DIOXIDE EMISSIONS

Comparing ETSAV carbon dioxide emissions data with these from the UPC, it has been observed that they were constant until 2005, with an annual average of 54.1 kg CO_2 /m^2, which is over the UPC annual mean consumption that is 40.9 kg CO_2 m^2.

Energy consumption in the ETSAV building has as main protagonist the HVAC systems consumption (mainly gas supplied heating) that is about 61% of the total of the billed energy. The 39% left corresponds to electricity consumption. But as far as carbon dioxide emissions are concerned, emissions due to electricity consumption represent 51% of these and makes equal to the emissions associated to the natural gas, since the emissions associated to 1 kWh of electricity are twice the emissions associated to 1 kWh of natural gas in Spain (I.D.A.E, 2005).

As it has been mentioned before, one of the main conclusions in the PhD thesis which monitored the consumption and the post occupancy of the building throughout the academic year (2002-2003), was that the low performance of heating system and inefficiency in its management increased final energy consumption by more than 30%. Therefore, management appeared as a possible strategy to reduce energy consumption already while further studying other parameters, such as energy demand or design and efficiency of the systems.

3 PRELIMINARY WORKS

In order to be able to operate immediately, some aspects had to be taken into consideration before defining the intervention criteria:

3.1 Characteristics of the heating system

All the (very limited) information available was compiled, and the plans and the characteristics of the system and its components were updated, especially paying attention to the regulation and circuits. This information allows to value –approximately- the system operation and to intuit how could be its response capacity to management.

3.2 The usual management profile of the heating system

Two sources of information were available: first – lacking an official management profile- the information provided directly by the responsible of building maintenance. Secondly, the automatic data obtained by online monitoring within the system SIRENA (Information system of power resources of UPC –CITIES, 2006), which provides historical and instantaneous consumption data -every 15 minutes- of the electricity and natural gas supplies. Both information revealed that the heating system management only consisted in turning on/off the whole system at the beginning and at the end of the winter period. Figure 1 shows how the heating system was working completely all day and night long and also during the weekends. Small variations correspond to demand variations. During the weekend, there are less variations since the building is almost empty, except for security staff and some students.

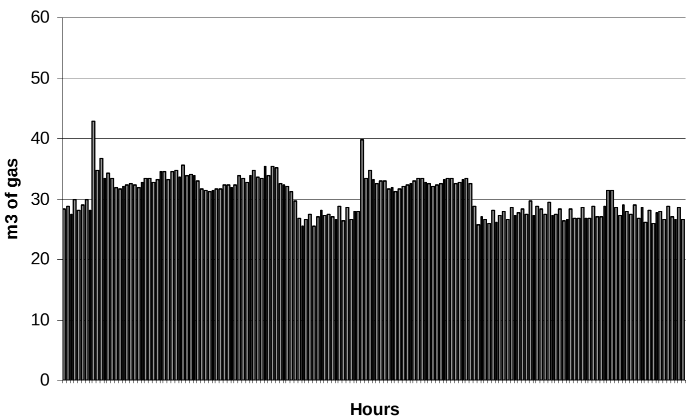

Figure 1. Natural gas consumption (m3 / 30 minutes), during one sample week in February 2006. Source: SIRENA System–UPC/CITIES

3.3 The occupancy profile

Before proposing actions on the heating system management, it was necessary to obtain data on theoretical occupation of the different building spaces during the autumn 2006– taking into account the number of students registered in every subject and prior distribution of lecture rooms, and considering that the professors remain in their department office at least during their lectures-. Based on all this information, a theoretical profile was drawn up (figure 2).

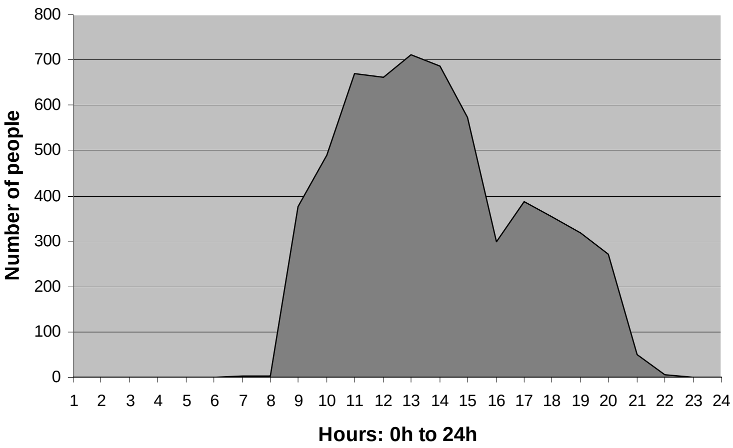

Figure 2. Theoretical occupancy profile for an autumn sample day in 2006. Source: self-made.

3.4 The climate variability

Climate data from national weather stations were compared to data from the local weather station installed in the building. Climatic variation was measured in degree days, and showed the trend of heating demand in the building.

When the characteristics of the heating system, the actual building occupation, and the variations of the climate were analyzed altogether regarding to the observed management, it was immediately apparent that there was no relation: the heating was working all day and night long no matter what the climate variations or building occupancy were.

3.5 The building and systems response capacity

Simulations of the hourly building indoor temperature were done with *Balanç Energètic* program (DE BOBES, 2006). The aim was to verify the possibilities for the heating system to preheat the building, and the role of the building thermal mass to delay the effect of the external climate variation –the building envelope response capacity- on the indoor temperature of the different spaces. On the basis of this analysis, the night period turn-off and the re-programming of on/off cycles of the heating system throughout the day could be defined, as to satisfy internal environment requirements reducing the energy consumption.

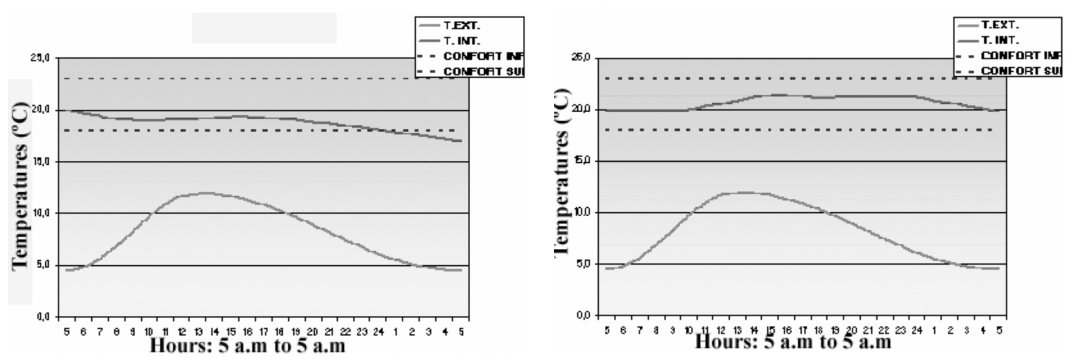

Figure 3. Indoor temperature evolution for a sample winter day. Left: evolution from an initial temperature of 20ºC. Right: evolution with stops of the heating contribution at midday and during the night.

4 ACTIONS CARRIED OUT

First phase: Actions at the beginning of the winter period: from November 2006 to January 2006 including non-academic activities.

First, the management of the heating system was adapted to the actual building operation, identifying the hours in which the occupation would be minimum or null and the systems could be programmed to turn off, without affecting the proper operation of the building. Secondly, it was adjusted to the climate variations, considering mainly if it was sunny or not, accordingly to the building characteristics (plenty of huge windows at south facade). Since no measurement equipment was yet available to record ambient temperature data, regular users poll was used as support to modify criteria and correct future actions.

As expected, this management profile could maintain the conditions of comfort (and even adapt them to a more adequate level) and allowed important energy saving. New consumption levels were more appropriate to the building demand. At the same time, the necessity to establish a model of management for the non-teaching/instructional periods within the heating season was apparent, since these periods included normal labor days, vacation, etc. Different typical days were identified, and a management profile was defined for each, including schedules to turn on/off the heating system and to turn on/off the artificial lighting. Spaces of preferred use in the building were identified as well. Lastly, and since normally students need to remain inside the building outside lectures schedule –nights and weekends- an only working-room was created to reduce the surface to heat and light out of the lectures schedule became smaller. Up to that moment, every room was ready to use all the day and night long by students.

These actions, despite bothering some users (problems of adaptation to new rules), contributed significantly to the saving in terms of consumption, fundamentally because they allowed to limit the heating and lighting surface to approximately 70%.

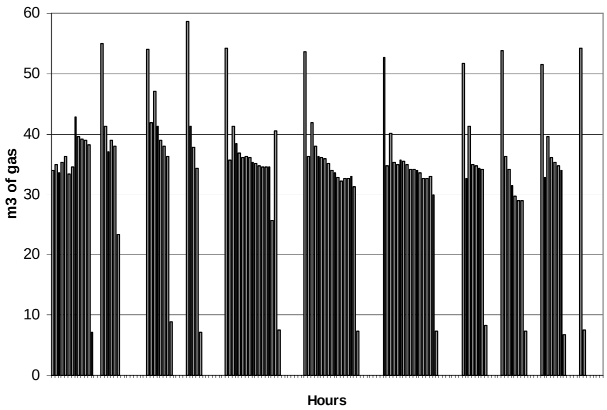

Figure 4. Management profile of heating system during the second week of December 2006

Second phase: Actions after the period of normal operation and to the end of winter (14th January-15th April 2007)

According to the obtained results, in this phase we went on working on the management of the heating systems, adjusting management profiles to building occupation rates, also considering the users' complaints and suggestions. A monitoring template was created to regularly register the system's operation mode. The template had to compile the following information:

- Outdoor temperatures: maximum, minimum and media per day
- Feed/ return water temperatures of the piping circuits
- On/off timetables for each piping circuit
- Comments

A data logger measuring surface temperature was incorporated to record feed/return water temperatures of the piping circuits as well as radiators' surface temperature. For measuring indoor comfort, another data logger would record temperature, humidity, barometric pressure and carbon dioxide. First of all -and taking into consideration the spaces in the building for which more problems and complaints had been noticed in the first phase of the work- the library was chosen for further analysis.

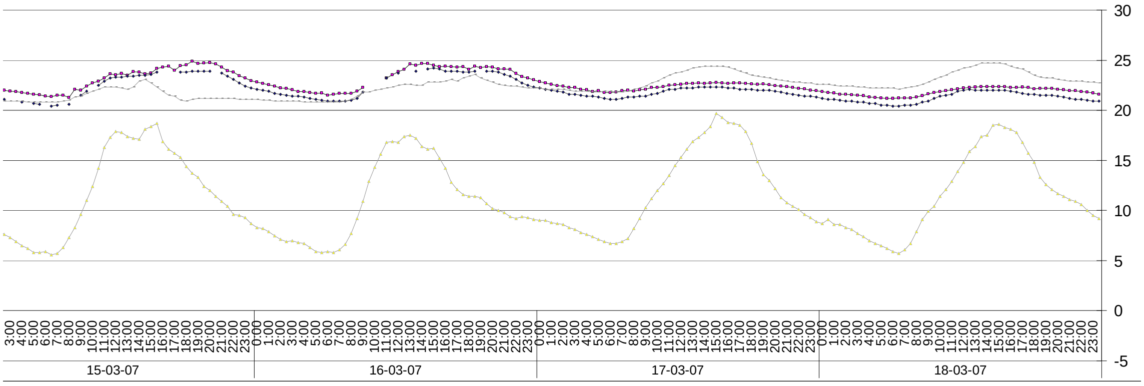

Figure 5: Example of indoor temperatures evolution: ETSAV Library -26th to 28th February 2006-. Light grey lower line shows outdoor temperature recording. Dark grey lines show indoor temperature for two different inside points.

Monitoring and registering helped to verify some considerations which where theoretical until that moment, such as the indoor temperature response to the on/off switch of the heating system or to the outdoor temperature variations along the day, and also to the variations of the occupancy rates. Finally and as a novelty for this second phase, lecture rooms assignments for every subject were reviewed to check if they were associated according to heating circuits. In accordance with professors and the School management team, the lecture rooms for some subjects had to be changed to favour and optimize management of heating and lighting systems.

5 RESULTS

Absolute value results are shown in terms of consumption index in table 1, where gas consumption during 2006-2007 heating period (from November 2006 to March 2007, both included) is compared to that of the same period in 2005-2006.

Table 1. Comparing the evolution of consumption and its associated emissions to reference index.

Period	kWh gas		Period degree day		kWh gas/m²		kWh/ degree day	
2005-06	1,035,280	100%	1510	100%	111.71	100%	685	100%
2006-07	644,381	62%	1241	82%	63.61	57%	519	76%

Period	tn CO_2		Period degree day		kg CO_2/ m²		kg CO_2/ degree day	
2005-06	211.2	100%	1510	100%	22.8	100%	140	100%
2006-07	131.5	62%	1241	82%	13.0	57%	106	76%

Comparing gas consumption of the operation period with that of the same period last year, energy consumption was reduced by 38%. Regarding to Carbon Dioxide emissions, 79.7 tons of CO_2 have been saved. Even when there is a significant absolute value reduction, it is necessary to distinguish the causes of the reduction and the incidence of the variations of the climate and of the building surface. Even when there is not a direct relation between the variations of climate and building surface and its energy consumption, in table 2 the same variations are applied to calculate approximately theoretical energy consumption. Therefore, the variations not attributable to climate or surface variations are considered attributable to management.

Table 2.

CO_2 tons due to gas consumption in 2005-06	211.2

"Expected" CO_2 tons due to gas consumption in 2006-07, considering that the building surface was augmented 9%	230.2
"Expected" CO_2 tons due to gas consumption in 2006-07, considering that the degree day variation was -18%	188.8
Real CO_2 tons due to gas consumption in 2006-07	131.5
CO_2 tons saved attributable to management in 2006-07	57.3

To sum up, 57.3 tons of the 79.7 CO_2 tons saved are attributable to sustainable management. In table 3, the month by month evolution is detailed and analyzed. The "expected" consumption for the 2006-2007 period, which is that of the year before - 2005-2006- adjusted to the degree day variation registered, is compared to the real consumption registered during this period. In March, where the number of degree days was higher this year (it was colder), energy saving was greater due to the more optimal management than during the rest of the months.

Table 3. Comparing the month by month evolution of the associated tons of CO_2 emissions to those in the same period in 2005-06.

	November	December	January	February	March
2005-06 consumption	32.9	52.1	47.4	46.9	32.0
Degree day variation	-8.6	-10.6	-8.3	-14.6	+5.7
"Expected" consumption 2006-07	24.3	41.5	39.1	32.3	37.7
2006-07 consumption	19.0	34.6	36.0	23.7	18.2
Saving due to management	-5.3	-6.9	-3.1	-8.6	-19.5

Compared in terms of building surface (square meters) to the historical evolution of the index for the ETSAV building in the winter period (November, December, January, February and March), consumption has been greatly reduced.

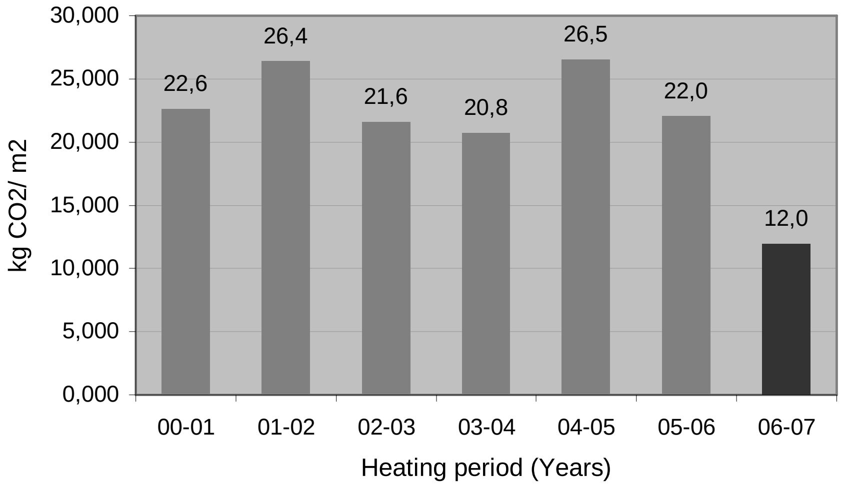

Figure 6: Evolution of the index: emissions associated to gas consumption for the ETSAV building in the winter period (kg CO_2/ m^2)

6 CONCLUSIONS

This work has proved that it is possible to check and validate the performance validity and suitableness for the management of energy systems and occupation rates in a building to reduce energy consumption and its associated CO_2 emissions. We have also verified that quick results can be achieved without high economical costs. Modifying only the management of the on/off switch of the heating system and without any investment in regulation systems, a new management can be set up. Even if this management could still be optimized, it aims for giving a better response to climate variations outside the building.

In this case, the operation strategy has been tested on a much defined period of the year and only for one of the energy appliances (heating), but similar strategies could be defined for another period of the year and for other energy systems of the building (cooling, lighting).

This work is still being developed and intends to achieve a second level of further analysis to identify other operation guidelines in different areas (the building skin/envelope, energy systems, use of programming).

REFERENCES

De Bobes, A. 2006. Balanç calculation program. Barcelona: De Bobes, A- Grup d'Arquitectura i Tecnologia- UPC.

I.D.A.E. Instituto para la Diversificación y Ahorro de la Energía. 2005.

López Plazas, F. 2006. About the use and the management like the main factors that determine the final Buildings Energy consumption. A contribution to reduce the environmental impact of the buildings. *PhD Thesis*. Barcelona: not published.

Molina, J.L. Álvarez, S. Velásquez, R. 2007. CALENER and LIDER Spanish energy consumption and energy demand evaluation software. Seville: Higher School of Engineering.

UPC Sustainability Center – CITIES. 2005. UPC Sostenible 2015. *Technical University of Catalonia Sustainable Development Plan*. Barcelona: UPC Sustainability Center – CITIES.

UPC Sustainability Center – CITIES. 2006. SIRENA: Information system of power resources. Barcelona: UPC Sustainability Center – CITIES. www.upc.edu/sirena

Housing and information society: integration of ICT in the existing housing stock

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ABSTRACT:
This paper describes an ongoing research concerned with the insertion of technology in domestic spaces, and more specifically in the existing housing stock. The study evolves with the premise that the insertion of technology in domestic spaces can reduce energy consumption and the environmental impact, in general, of the use and functioning of buildings, while contributing for improving the quality of life of its inhabitants. It also considers that the rehabilitation of existing buildings and urban areas is preferable to the construction of new housing, if one is concerned with the environmental impact of construction activity in the city. The study focus on the buildings built in Lisbon during the period 1950-1970 which accounts for a considerable part of the existing housing stock. The goal is to identify the strategies to follow in the refurbishment of these buildings so that they fulfill the requirements of modern life.

1 CONTEXT

This paper describes a Ph.D. research that is currently being developed at Instituto Superior Técnico (IST) and at the National Laboratory for Civil Engineering (LNEC) on the subject of "Housing and Information Society: study for the integration of Information and Communications Technologies in existing residential areas". It builds on a preliminary project called "Housing for the future" which was developed at LNEC a few years ago.

The Ph.D. thesis sets off with the premise that the future of real estate market in Portugal will require the rehabilitation of existing residential areas and that it will be of utmost importance the incorporation of Information and Communications Technologies (ICT) in the quest for added sustainability, social integration, support for elderly and people with reduced mobility, and in the improvement of quality, comfort, and adaptability of housing.

2 PROBLEM

In an era in which information and energy have structural roles in society, it is herein proposed a reflection on the transformation of the ways of life occurred over the last decades and its impact on the demand of new housing functions and types. The incorporation of new housing functions calls for a new approach to the design of domestic space, in which the diversity of conventional spaces must interact with the inclusion of new multifunctional spaces that accommodate activities such as telework and telehealth in order to respond to the growing demand of information access and of comfort in homes.

In addition, it is hereby acknowledged that the construction industry is, of all human activities, the main responsible for energetic consumption, and therefore, it is necessary to reduce the negative environmental impact of buildings both in the sheer construction, in maintenance, and in rehabilitation.

Considering that Lisbon has a high percentage of vacant housing, and that the existing housing infrastructures are sufficient to respond to the housing demand in the city (vide Table 1), the problem that concerns us is how to rehabilitate existing buildings and supply them with the specifications that fulfill the contemporary needs of comfort, homeliness, and information access, among others.

3 HYPOTHESIS

Lisbon's resident population has been diminishing at a fast rate, currently amounting to 564,000, after having dropped 14.9% in ten years time (INE 2002). The loss of resident population has been followed by a progressive degradation of the city's housing infrastructure with the consequent growth in the number of vacant houses.

The extent of the vacancy problem is illustrated by the fact that the full occupancy rate of the existing, under construction, licensed and planed housing is of over 930 thousand habitants (Pinho 2005).

As shown in Table 1, the vacant house figures in 2001 were considerably superior to the housing shortage in the city. In fact, 9% of Lisbon's housing is utilized for seasonal residence and 14% is vacant (CML 2002). In addition, 51% of the traditional residences in Lisbon are occupied under capacity and only 16% are filled over capacity.

Table 1 – Housing quantity deficit and vacant housing by NUTS II, Lisboa, 2001. (Rodrigues 2002)

	Portugal	Lisbon
Unconventional housing	27,319	11,960
Traditional families resident in hotels and in communions	8,178	1,981
Shelters for families residing is shared occupation methods	68,299	21,376
2% of the traditional resident families	73,015	20,113
Total deficit	176,811	55,430
Vacant housing	543,777	149,327
Vacant housing available in the market	185,509	58,403

The above figures suggest that more than the construction of new buildings we need to rehabilitate existing ones. However, in 2002, the activity of conservation and rehabilitation in Portugal represented a mere 6% of the construction trade (the european mean was 37%) (Aguiar 2007). Statistics indicate that, although rehabilitation is now a very popular subject, new construction continues to largely dominate the housing market.

The reduction of the environmental impact of buildings inevitably calls for the rehabilitation and reutilization of existing infrastructures. This fact seems to be well accepted by the consumers, but is not echoed by the construction industry, which seems ill prepared for responding to such a demand. It is not uncommon to find plans for urban renovation with conversion of use in historical areas that are advertised as urban rehabilitation, while focused on sheer maintenance of building facades, while destroying all of its interiors to construct new structures., These plans are purposefully misleading as they attempt at taking commercial advantage of public interest in sustainability and heritage conservation.

The construction industry is the main responsible for energy consumption and it is, therefore, necessary to reduce the negative environmental impact of buildings. The construction process has a huge negative impact on the environment for it consumes and uses up considerable natural resources. Construction alone, on the one hand, generates the emission of polluting agents and, on the other, creates waste that to be processed requires, in turn, more consumption of resources. This consumption cycle proceeds during the use of the building and it aggravates itself towards the end of its lifespan. Not only does this phenomenon occur at the building level but also at the city level (Mourão 2005).

The use of ICT and of domotic in the dwelling use and maintenance period may also contribute for a reduction of the environmental impact of buildings. Domotic may protect the environment by optimizing the processes involved in use and maintenance to allow a more rational use of natural resources, such as energy and water, and a more rational set up of the inhabitable space. The most common domotic specifications and systems that favor energetic efficiency of the building are energy management, blinds control, lightning control, heat and cooling systems control, automatic ventilation control and the use of ICT to remotely control the house and energy the consumption.

4 OBJECTIVES AND METHODOLOGY

The ongoing research has the following objectives:

- Studying and defining the functions of housing in the current Information Society (IS), through the analysis of the impact produced by the integration of ICT in the dwelling space, both on spatial and functional organization, and building methods;
- Determining the adequate set of ICT to incorporate in the dwelling spaces, so that it values sustainability and the social integration of citizens, while making it possible to progress towards a fine tuning of solutions, adapted to each household, according to its present and future needs. Such set of ICT would be applicable to the dwelling as well as the building, not only in new construction but in the existing residential areas's rehabilitation as well;
- Defining design guidelines to support architects in the adaptation of existing residential areas with the purpose of ICT incorporation, thereby allowing those professionals to balance new dwelling trends with sustainable requirements and economic feasibility.

The first stage of the research is concerned with a literature survey of studies on the effects of architectural transformations that are emerging as a result of new ways of living that imply increasing housing requirements. Out of the aforementioned requirements, emphasis will be given to the ICT impact on spatial and functional organization caused by telework and the need to attend to a growing number of seniors and people with reduced mobility.

The ICT also has impact on construction, since the increasing requirements of information access and comfort in housing have called for new changes in the building's image as well as in the ways of thinking and defining the basic infrastructure. The necessity of networks and information systems that require physical space to run the cables between components of the domotic system, together with the tendency to make the housing spaces more flexible and adaptable, demand different construction solutions that require study.

The second stage of the research aims at identifying the adequate set of ICT to incorporate in, a dwelling considering its household profile.

Due to the fact that there is no single technological solution that fits all, it becomes necessary to define an adequate set of ICT and domotic that can be integrated in each home and that promotes environmental sustainability and social integration of its inhabitants. In addition, the set should be able to adapt to the evolution of the household. This issue will be addressed first by considering several households and then by identifying the corresponding patterns of ICT.

The study will use as a case study a specific housing stock in Lisbon, to make it possible to:

(1) To gather data referring to the current housing types, its spatial and functional organization, and its building characteristics;

(2) To assess existing problems:

  (a) at a functional level, by matching the spatial and functional patterns proposed in the original project, with current requirements when articulated with the introduction of ICT and domotics in housing.

  (b) at a building level, by matching existing building characteristics and infrastructures with present needs, namely as far as ICT are concerned.

(3) To propose generic solutions that satisfy current demands and that may be applied to other similar buildings.

Due to the large variety of buildings that require rehabilitation in Lisbon, it was necessary to select a specific stock to use as a case study. The housing stock built in the 50's and 70's of the last century was chosen on account of what it represents (circa 36% of Lisbon's buildings were constructed between 1946 and 1970 – vide Table 2) and its expectancy of rehabilitation in a short term. According to the 2001 census, 55% of the buildings constructed in Lisbon between 1946 and 1970 needed improvement repairs, and 24% was considered to be in medium to highly deteriorated conditions.

Table 2 – Housing according to the period of construction. (CML 2002)

Period of construction	Lisbon
Built before 1919	18,28%
Built between 1919 e 1945	23,66%
Built between 1946 e 1960	22,01%
Built between 1961 e 1970	14,21%
Built between 1971 e 1980	8,96%
Built between 1981 e 1985	2,73%
Built between 1986 e 1990	2,94%
Built between 1991 e 1995	3,17%
Built between 1996 e 2001	4,04%

Table 3 – Conventional housing according to occupation form in the period of construction between 1946 and 1970. (CML 2002)

Occupation form	Lisboa
Occupied – usual residence	79,97%
Occupied – seasonal or secondary use	8,80%
Vacancy – for sale	0,94%
Vacancy – for rent	2,22%
Vacancy – for demolition	0,23%
Vacancy – others	7,84%

The type of building that was chosen is commonly labeled tenement building" (subsequent to the 2nd world war) and it presents a "right and left" displacement (vide Figs. 1-2), variable heights with a four-flour average, and a preponderance of reticulate concrete structure filled with masonry walls.

In the two decades that this study concerns, it was observed a slow increase in the height of buildings, as well as the employment of new construction techniques and the increasing use of concrete. According to the 2001 census, 46% of the buildings built between 1946 and 1960 have a concrete structure, and in the period between 1961 and 1970, the figure rises to 63,1% (INE 2002).

The type emerged in Lisbon after 1951, when the General Regulation of Urban Buildings (or RGEU) was created, and it influenced the 1967 Regulation of Concrete Structures (or REBA) and its subsequent revised regulation, approved in 1983, called Regulation of Reinforced and Pre-stressed Concrete Structures (or REBAP).

The dwellings are essentially very similar to each other, and present mainly two and three bedroom layouts, with relatively small, highly split areas.

Fig. 1 - Multi-ocuppancy habitational building in Lisbon, Av. de Roma, decade of 1950.

Fig. 2 - Multi-ocuppancy habitational building in Lisbon, Bairro de Alvalade, decade of 1950.

5 REHABILITATION AS A SUSTAINABILITY STRATEGY

The city of Lisbon needs to reassess its housing policy so that the main concern becomes to rehabilitate the existing housing infrastructure rather than constructing new buildings.

As mentioned above, the high number of vacant buildings and houses in the city, along with the fact that they have already restrained the use of the soil and usually have a long-term use expectancy, are good and undeniable reasons why the addition of houses should preferably be made by the rehabilitation of old ones (both function wise and construction wise) and the reutilization of the existing infrastructure.

The reutilization of existing buildings contributes for urban sustainability, since it renews, regenerates, and rehabilitates the city.

To reclaim residential use for the city's downtown allows the regeneration of urban areas, while bringing new population to the center, making the most of the existing infrastructures, making proper use of the already conditioned soil, and reducing voids in the city, thereby endorsing full city occupancy.

From a financial viewpoint, rehabilitation also reduces investment because of the exceptionally high value of land for new residential buildings prevalent within cities.

According to Daniels (2000), *"transport is the next major consumer of energy after buildings."* Hence, drawing new population to the city center is a factor that endorses the existing transportation infrastructure use while reducing the distance between home and the work place.

The major drivers for rehabilitation are the following: it is a viable solution to the need for complying with high environmental standards, it overcomes the scarcity of available land in the city, it depletes renewable and non-renewable resources (materials, water and fuel) to a lesser extent, and it reduces the waste in construction by reducing demolition.

6 FUNCTIONAL REHABILITATION OF LISBON EXISTING RESIDENTIAL AREAS

Although the existing housing stock in Lisbon has the potencial to draw more population to the city, the truth is that 55% of dwellings built in the studied period requires construction rehabilitation (INE 2002). The need to rehabilitate these dwellings from a functional perspective is also vital, but perhaps not as easy to quantify as it is to understand.

The existing housing stock does not fulfill the present lifestyle's needs, both function wise and comfort standards wise. The selected housing stock, now a few decades old, present several problems that jeopardize its functional and constructive performance, particularly in terms of comfort. This situation is the result of a set of factors, of which we underline the following: lifestyle changes that demand new needs and requirements; and the inexistence of regular repair works, which cause deterioration of materials, components and utilities.

One premise of the current study is that the functional adaptation of houses to new ways of living and to the diversity of current needs and requirements can be facilitated by the incorporation of ICT and domotic. The rehabilitation concept that is herein supported involves the conservation of rehabilitated buildings and the incorporation of ICT for adaptating its use to the demands of today's Information Society.

Over the last decades, social and technological changes have affected the ways of living and the requirements and functions of housing. These have changed the families' lifestyle, thereby making traditional house types inadequate to the contemporary society's demands. Although the concept of family unit still represents the majority of homes, the crescent number of other forms of cohabitation and new ways of grouping individuals cannot be ignored.

The integration of new functions in homes calls for new approaches to the design of domestic spaces, in which it is necessary to incorporate the diversity of conventional spaces to the multiplicity of new-functions created by the emergence of activities like telework.

In addition, the technological dependence that characterizes the current civilization, along with crescent demands of access to information and comfort, claim for the incorporation of a set of support infrastructures in the dwellings.

7 INCORPORATION OF ICT AND DOMOTICS IN THE REHABILITATION OF EXISTING RESIDENTIAL AREAS

Home networking and automation systems can have a very important role in contemporary dwellings because of the benefits they bring to residents. The incorporation of intelligent features adds value to homes and enhances the lives of those who inhabit them while contributing to better housing management.

There are a wide variety of automation and control systems, from basic mood lighting systems to full house automation that can be viewed and controlled from anywhere in the world. In this paper, we list the services and functions of domotic that can contribute for increased sustainability through better housing management.

Domestic automation is composed of a series of domotic systems (or services) that perform several interlinked functions. The main systems can be described as follows:

- Security and safety: intruder alarms, central locking of doors and windows, fire alarms, smoke and CO_2 detectors integrated with other systems such as lighting and locks;
- Comfort: environmental control, acclimatizing appliances control, appliance programmed timetable, lighting control, mobile phone alarm connection, medical alarms, and others;
- Management of energy systems: remote metering, energy read-out, effective heat and cool control, lightning control, electric appliances control, this systems encourage sustainability through improved use of energy;
- Information and Communications: open multi-media communications infrastructure for TV, telephone and computers, and house automation controlled from anywhere in the world;
- Entertainment systems and environments: online games, interactive digital TV solutions, home cinema, video-on-demand, and so on;
- Central control: central computer control of all systems;
- Disability systems: video cameras, CCTV and access control systems, alarms, and detectors for disabled, elderly, and sickness people or maternity.

First and foremost, it is important to address domotic as a means to manage home electronic appliances and to complement, not to substitute, passive solutions. As an example, we can point out that the incorporation of efficient heating and cooling systems, controlled by domotic, should not let us overlook the need to improve building insulation; instead, domotic should function as a complement in those situations in which passive solutions are insufficient or difficult to achieve, as it is often the case in rehabilitation.

It's necessary to consider energy saving strategies that can be applied to existing buildings in rehabilitation. The intelligent technologies do not have to be confined to new building design.

In Portugal, housing represents around 13% of the country's energy consumption and it is breakdown as follows: 50% for kitchens and heated waters, 25% for cooling and heating, and 25% for lighting and appliances (Mourão 2005).

The use of solar passive strategies in existing housing frequently fails to satisfy the higrotermic and luminic requirements, mainly because design did not attend to the matter. This requires increasing comfort standards using active systems, but balancing them by limiting internal heat gains through the use of more efficient heating, cooling systems, and lighting systems.

In such contextss, better control systems for heating and cooling management are fundamental and can promote energy efficiency.

If a house can collect detailed information relating to environmental conditions outside and inside the house, this information can be used in domotic control decisions. For example, an efficient artificial lighting system has the ability to deactivate or dim itself in response to adequate natural lighting levels (Wigginton 2002).

There several domestic automation solutions that can be used for cutting energy consumption, including presence detection devices, solar control systems (intelligent control of blinds and other protective shades that can be lowered, raised and tilted according to the detected presence of the sun), and computer controlled ventilation by motorized opening of doors and windows. The specification of high and low temperature intervals and the increase of a few degrees in such intervals allow better energy management and it can be performed by a domotic system.

Systems that promote an efficient use of non-renewable energy sources, such as the split period power counter, the task ranking controller, and integrated systems for reduction and control of energetic consumption, are also domotic strategies in the sense that they aim at better energy management of the house. In addition, systems that use of renewable energies, such as solar water heaters, photovoltaics and wind turbines also can be integrated into domotic systems.

The information and communications systems are required in homes for two purposes: to improve the performance of the building through effective management of automation devices, and to help improving the lives of people within the building. For example, installing a cabling network at both the building and flat levels will allow residents to benefit from new media, such as cable television and broadband internet access with no need to use wireless technology or ICT infrastructures attached to the facades.

As an alternative course of action, the intelligent house, equipped with ICT and computer means that anticipate and respond to its resident's demands, can also serve the elder and people with reduced mobility, as well as other groups of habitants, in such a way as to secure their comfort and protect their safety, by allowing them to surpass obstacles and supporting the execution of their daily tasks.

For houses that require a level of control for disabled or elderly residents, the market offers nowadays numerous assistive technologies that can be designed to evolve as the resident requires more assistance around the home.

The smart house that provides assistive technologies to help living more independently can assist with:

– safety and security maintenance, such as effective alarm call and smoke, heat, water and gas detectors (Dewsburry 2005);
– automation or remote control of tasks that an individual is unable to perform, such as turning lights on and off, and opening or closing of doors, windows, and blinds;
– communication (external and internal);
– proximity or motion sensing;
– fall detection;
– assistance with food preparation and storage;
– unobtrusive ADL monitoring and assessment, that is, the use of control systems to provide passive and unobtrusive monitoring of residents and check that regular habits are kept;
– vital signs monitoring.

8 CONCLUSIONS

Information is playing an increasingly important role in our lives and, as a consequence, ICT is changing the ways in which we inhabit spaces. Recent intelligent technologies aim at maximizing the use of information with the dual goal of providing the house with increased information access and comfort through the use of automated control systems.

However, the crescent demand of domestic comfort is often incompatible with the environmental sustainability that we try to promote. The excessive use of heating and cooling systems, as well as, of other electrical appliances, together with the excessive use of water, are factors that improve the quality of the dwelling environment but push us away from environmental sustainability. Intelligent technologies can play an important role in energy saving strategies and can be introduced in existing buildings as part of their rehabilitation process.

In addition, the rehabilitation of Lisbon's existing housing stock must fulfill new space-use requirements demanded by the new, information age lifestyles. Such rehabilitation must also be guided by ecological, social, and economical sustainability. Ongoing research aims at identifying the strategies that permit to achieve an adequate balance between these conflicting goals.

ACKNOWLEDGEMENTS

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REFERENCES

Instituto Nacional de Estatística (INE) 2002. *Recenseamento Geral da População e Habitação – 2001 (Resultados Definitivos)*. [em linha]: INE. [Consultado Maio 2006]. Disponível em WWW: <URL:http://www.ine.pt/censos2001/>

PINHO, Ana; AGUIAR, José 2005. *Reabilitação em Portugal. A mentira denunciada pela verdade dos números!* Arquitecturas, nº 5, Outubro. Lisboa: Arquitecturas.

Câmara Municipal de Lisboa (CML) 2002. *Dados definitivos do Censos 2001 – "Grandes números"*. [em linha]: Câmara Municipal de Lisboa. [Consultado Março 2007]. Disponível em WWW: URL:ulisses.cm-lisboa.pt/data/002/006/pdf2/texto.pdf

RODRIGUES, Duarte 2002. *A evolução do parque habitacional português: Reflexões para o futuro*. [em linha]: Instituto Nacional de Estatística. Disponível em URL: http://www.ine.pt/prodserv/estudos/ficha.asp?x_estudoid=289#

MOURÃO, Joana; BRANCO, João Pedro 2005. *Sustentabilidade Ambiental e Áreas Residenciais*. Lisboa: LNEC, Março. Edição Restrita.

ELOY, Sara; PLÁCIDO, Isabel 2005. *Novas Tecnologias da Informação e Comunicação na Habitação*. Lisboa: LNEC. Edição Restrita.

PRAGNELL, Mark; SPENCE, Lorna; MOORE, Roger 2000. *The market potential for Smart Homes*. York: Joseph Rowntree Foundation.

HARPER, Richard (ed.) 2003. *Inside the smart home*. Londres: Springer.

WIGGINTON, Michael; HARRIS, Jude 2002. *Intelligent Skins.* Architectural Press.

DANIELS, Klaus 2000. Low-*Tech Light-Tech High-Tech. Building in the Information Age.* Basel: Birkhauser Publishers.

AGUIAR, José; PAIVA, Vasconcelos; PINHO, Ana 2007. *Guia Técnico de Reabilitação Habitacional*. Lisboa: LNEC, INH.

Dewsburry, Guy 2005. *Smart homes - Technology for Living*. Conference on Assistive Technology. [em linha]: The Queen Elisabeth National Spinal Injuries Unit, South Glasgow University Hospitals Trust, In conjunction with the National Spinal Injuries Unit, Momentum Scotland, MASCIP. Disponível em URL: www.smartthinking.ukideas.com/Momentum%20Glasgow%20Smart%20house%20April%202005.pdf

Thermal rehabilitation of a student's hostel belonging to the Politehnica University of Timişoara

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ABSTRACT: The student's hostels located in Timişoara-Romania were mostly built from 1970 to 1980 with the adoption of minimum solutions for the thermal insulation required at the time. The hostels are heated by using a district heating station. The use of the buildings without general repair work has led to the occurrence of certain damages, especially because of the asweat on the walls.The technical department of the university has promoted and sustained the improvement of the energetic performances of the hostels located in the campus area.
The paper presents one student hostel before and after thermal rehabilitation, along with the solution adopted and the economical study performed in order to sustain the execution of the constructional works. The solutions adopted referred to the improvement of global thermal resistance of the envelope elements in order to reduce the pollution and the energy loss.

1 INTRODUCTION

The "Politehnica" University of Timisoara, Romania is one of the largest and best-known technical universities in Central and Eastern Europe. Located in Western Romania, The "Politehnica" University attracts students both from the city and form the neighboring regions.

During the university years, the administration offers students the possibility to find accommodation in the campus. The students' campus located in the city centre hosts over 25 hostels. During a university year, over 5,000 students can be accommodated in the hostels of the Politehnica University.

The administration of the University is permanently concerned with the improvement of the accommodation offered to the students, therefore, the investments have been directed especially to the rehabilitation of the students' hostels. This activity has been carried out during the latest 3 years and the interventions were focused on the reconstruction of the finishing works, as well as the improvement of the comfort conditions. Taking into account the age of the buildings and the installations thereof, the works aimed at the total change of the installations, the complete remaking of the finishing, the improvement of the thermal insulation and installing of one thermal station for each hostel.

2 PRESENTATION OF A TYPICAL STUDENTS' HOSTEL

One of the students' hostel that has been rehabilitated is Hostel 20C (Fig.1). The building is included in the accommodation park of the Politehnica University of Timisoara, being erected in 1978. It has a basement, a ground floor and five storeys, each storey hosts ten apartments, each apartment includes two rooms, a shower room and a water closet. The apartments also have a hallway, with two sinks. Figure 2 shows the functional architecture of one apartment.

Figure 1. General view of hostel 20C

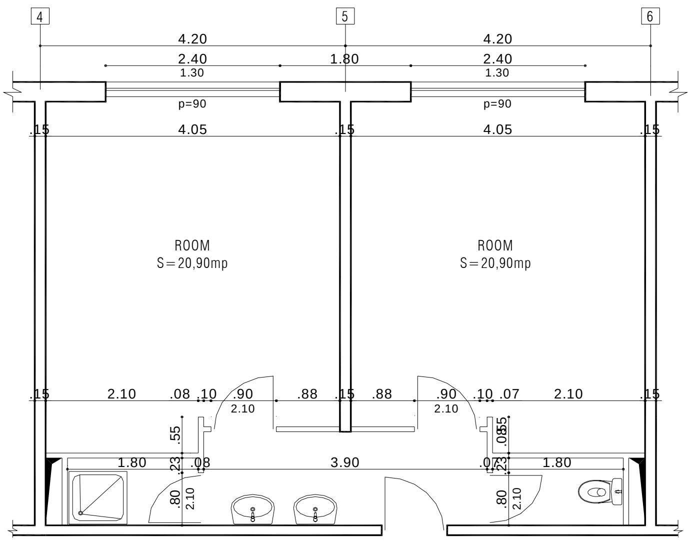


Figure 2. The functional architectural structure of one apartment

On each floor, at the end of the hallways, there are the stairways and 2 pantries, nowadays also used for students' accomodation, although, in the past, they contained electric cookers or washing machines. As a matter of fact, the hostel is part of a chain of 4 similar hostels, related by linking buildings that include the ground floor and two storeys and host the students' reading rooms. The total surface of the building is about 6566 square meters (out of which the 938 square meters of the technical basement). The surface of one floor is about 938 square meters.

From the point of view of the structure, the hostel has a vertical resistance structure composed by structural reinforced concrete walls made up of large prefabricated panels for the facade walls and cast in place structural reinforced concrete interior walls. The horizontal structure is made of reinforced concrete prefabricated panels. The partition walls between the rooms hallways and the bathrooms respectively the shower rooms are non-structural, made of reinforced light weight concrete blocks. The original roof was initially a terrace-roof. Nowadays, it has a sloping roof. The roof envelope and the envelope accessories are newer than the building, being built after 1985. The interior finishing of the walls is done with lime mortar coating and clay painting, that has to be entirely remade, due to the high level of degradation. On the building side that shows to the park nearby, in several rooms there have been noticed mouldiness caused by the insufficient thermal insulation and to the existing thermal bridge (Figure 3a). The access hallways to the hostel rooms are partially covered with tiles, that show degradation and need to be entirely replaced. The bathrooms also have tiles that are damaged (Figure 3c). The floor of the main hall is covered with cast mosaic or cast mosaic plates. The floors of the rooms are covered with linoleum, badly run out (Figure 3b). The carpentry is old and badly damaged (Figure 3d).

a. Mouldiness on the exterior walls

b. Degradation of the linoleum floors

c. Degradation of the tiles and piping

d. Situation of the exterior carpentry

Figure 3. Aspects of the hostel's status

3 EVALUATION OF THE ENERGETIC PERFORMANCES OF THE EXISTING BUILDING

In view to the rehabilitation of the hostel, there has been performed a technical and thermo-energetic expertise in order to decide upon the intervention measures. From the structural point of view, the building can take both gravitational and horizontal (earthquake) loads. No structural damages have been noticed during the operation along the years. The thermal-energetic expertise aimed at establishing the level of the energetic performances of the existing building and to decide upon the principle solutions for rehabilitation. The heating of the hostel was done by the centralized city system.

4 REHABILITATION OF THE STUDENTS' HOSTEL

4.1 *Structural solutions*

The good behavior in time of the structure led to the lack of imposing special rehabilitation steps. But the proposal to install the hostel's own heating station required the consolidation of the floor over the basement and the ground level, due to the increased loads brought to the installations. The floor intended to support the boilers of the heating station was made of reinforced prefabricated concrete 9 cm thick, designed for an effective load of 150 daN/m^2. The structural solution adopted was to build an additional floor over the existing one, the new floor coming with cross beams able to take over the vertical concentrated loads from the equipments and the elements of the station. In order not to overload the existing floor, between the beams of the new floor and the old floor there was laid a layer of polystyrene. The composition details of the proposed solution are shown in Figure 4.

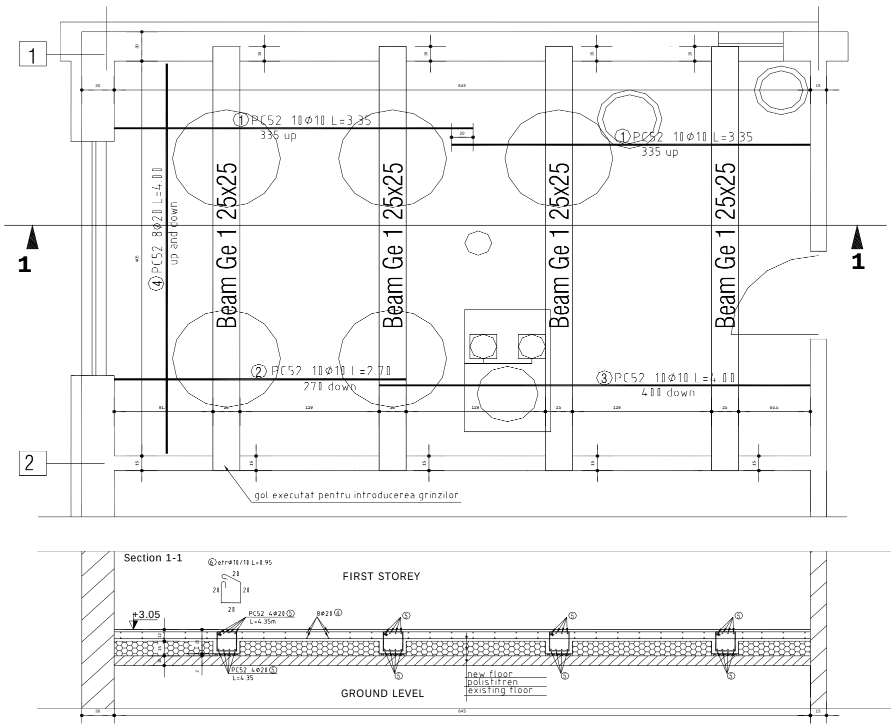


Figure 4. Details of the proposed structural solution

4.2 *Solutions for thermal rehabilitation*

The investigation performed led to the conclusion that exterior envelope elements were built as follows (from the interior to the exterior):

- The side panel, concrete 20 cm, Autoclaved Aerated Concrete 12.5 cm, concrete 6 cm, mortar coating 1.5 cm (Precast Panel Type 1);
- Between the windows: concrete 20 cm, Autoclaved Aerated Concrete 12.5 cm, mortar 0.5 cm (Precast Panel Type 2);
- The bottom panel under the window, concrete 10 cm, Autoclaved Aerated Concrete 12.5 cm, concrete 7.5 cm (Precast Panel Type 3);
- The front walls: concrete 15 cm, Autoclaved Aerated Concrete 12.5 cm, face brick work 7.5 cm (Precast Panel Type 4);
- Double-winged coupled windows;
- Single-wing windows;

- Metallic single-wing doors;
- The flat roof over the fifth storey: concrete 10 cm, vapour barrier made of bituminous membrane of 0.02cm, autoclaved aerated concrete 12.5 cm, cement flooring 10 cm, waterproof membrane with 5 layers of about 1cm thick;
- The floor over the basement, linoleum 0.5 cm, 10 cm cement flooring, 10 cm reinforced concrete.

Table 1 shows the heat flow resistances of the envelope elements, the minimum required resistances, the ratio between them and the average thermal resistance of the building.

Table 1 – Resistances to heat flow – current situation

Type	R' [m^2K/W]	R'_{nec} [m^2K/W]	R'/R'_{nec}	$\overline{R}$ [m^2K/W]
Precast Panel Type 1	0.82	1.4	0.58	
Precast Panel Type 2	0.78	1.4	0.55	
Precast Panel Type 3	0.77	1.4	0.55	
Precast Panel Type 4	0.9	1.4	0.64	
Double Coupled Window	0.39	0.5	0.78	0.61
Simple Window	0.17	0.5	0.34	
Metallic Door	0.17	0.5	0.34	
Roof floor	0.87	3.00	0.29	
Floor under basement	0.39	1.65	0.23	

In order to evaluate the energetic classification, there has been calculated the normal annual heat necessary and the normal annual heat necessary for hot water preparation. Based on the values obtained, there was established the energetic classification according to the Romanian codes in force (Figure 5).

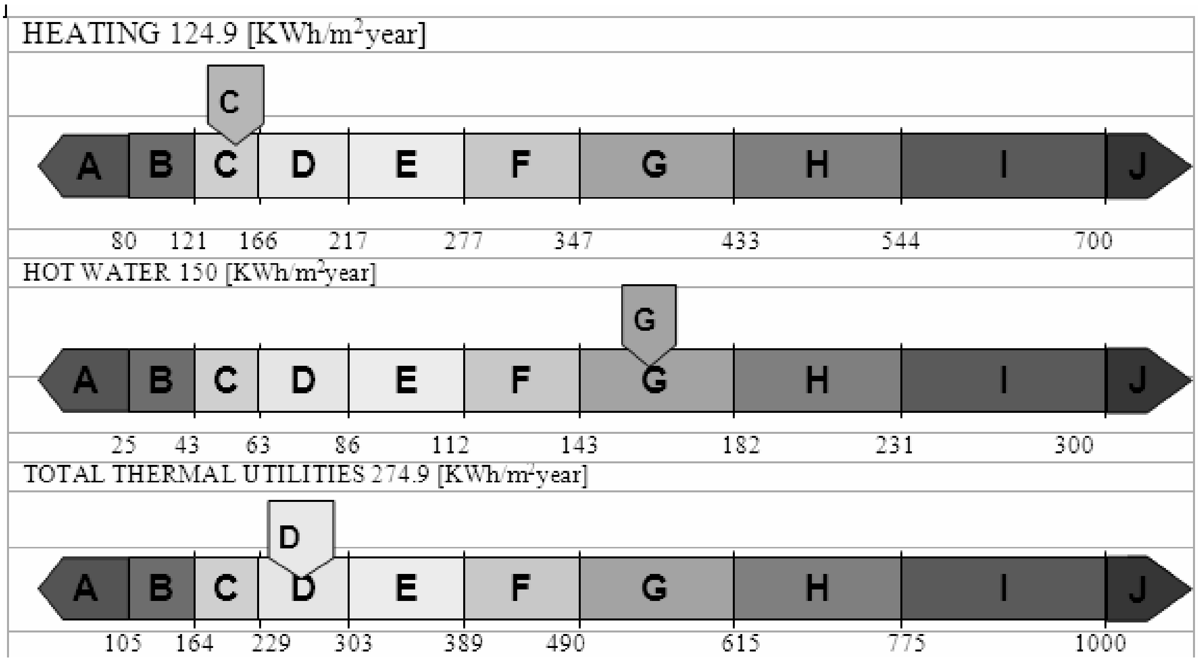


Figure 5. Energetic classification of the existing Hostel C20

Because all the envelope elements of the building show short-comings regarding the resistance to heat flow, the following measures have been proposed, in order to improve the performances of the building. Thus, concerning the exterior walls, there was proposed the execution of a thermal system, composed of an additional thermal protection applied to the exterior, made of polystyrene, over which there is applied a finishing layer on a support of glass fibre. The building will be painted in pastel colors. The existing carpentry will be entirely replaced by plastic carpentry and thermally insulated windows. For architectural reasons, the face brick facades will not be altered, in order to comply with the urban regulations of the area. The floor over the basement will be insulated by the application of a layer of polystyrene 5 cm thick, and the floor over the highest storey will be insulated by the application of a polystyrene layer 10 cm thick and a cement flooring minimum 2 cm thick. Based on the solution proposed, there have been recalculated the resistance to heat flow of the envelope elements respectively the average thermal resistance of the building. The values obtained are shown in Table 2.

Table 2 – Resistances to heat flow – current situation

Type	R' [m²K/W]	R'_{nec} [m²K/W]	R'/R'_{nec}	$\overline{R}$ [m²K/W]
Precast Panel Type 1_R	2.17	1.4	1.55	1.37
Precast Panel Type 2_R	2.13	1.4	1.52	
Precast Panel Type 3_R	2.11	1.4	1.50	
Precast Panel Type 4_R	0.9	1.4	0.64	
Double Window_C	0.5	0.5	1	
Thermoinsulated Door_C	0.5	0.5	1	
Roof floor_R	3.49	3.00	1.16	
Floor under basement_R	1.65	1.65	1	

The analysis of the resistance to heat flow obtained after the application of the thermal rehabilitation solutions proved that the resistances to heat flow of the envelope elements exceed the minimum values required, except for the walls of the Eastern and Western facade. Although the solution of the application of a thermo-insulating layer over the interior sides of these walls could be adopted, this has not been done, since the areas neighbouring the non-rehabilitated walls housed the staircase and the common pantries. After the rehabilitation, the average resistance to heat flow of the building doubles.

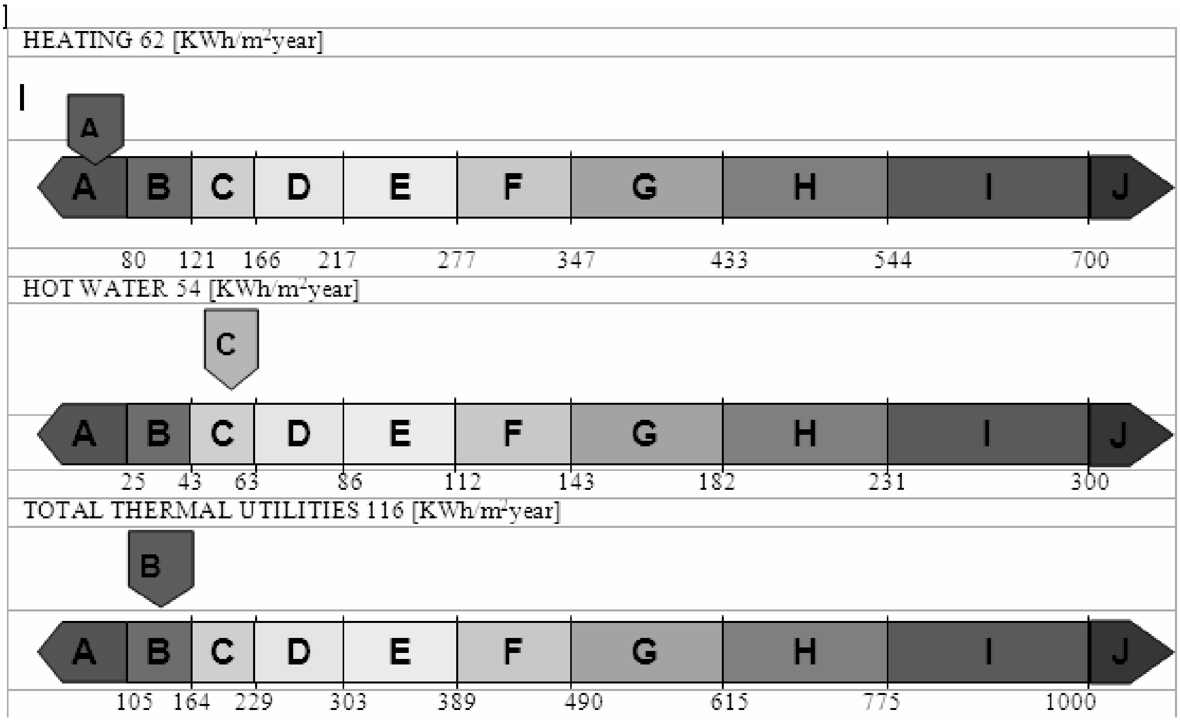


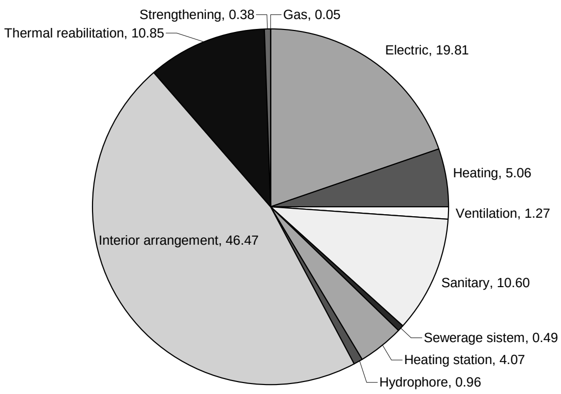
Figure 6 – Energetic classification of the Hostel C20 in the proposed solution

In order to improve the heating system and to reduce the losses, there has been proposed the installation of a heating station on gas, the overall replacement of the radiators and the heating system. The proposed pipe lines were made of high density polypropylene, pre-insulated in the basement of the building. Each distribution casing will have devices for evacuation and cleaning.

Figure 6 shows the new classification of the thermally rehabilitated building.

5 ECONOMICAL STUDY OF THE INVESTMENT. CONCLUSIONS

The evaluation of the investment was performed on the basis of the quantity of the determined works according to the proposed interventions. The graphs in Figure 7 show the distribution of the expenses by specialties.



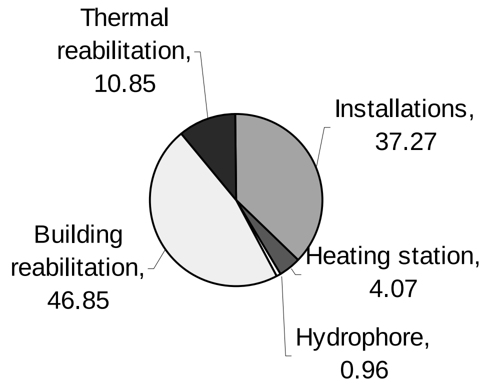


Figure 7. Distribution of the investment costs on specialties [%]

5.1 *Comparative study concerning the energy consumption*

Based on the theoretical evaluations performed, there can be noticed that the thermal rehabilitation led to the reduction of the heat consumption necessary for the heating of the area by nearly 50% from the initial consumption. The reduction of the total energy consumption is by more than 50% of the initial consumption. The heat consumption for the heating of the areas reduces because the average thermal resistance of the building doubles and because of the thermal station located within the building, thus reducing the losses along the distribution network.

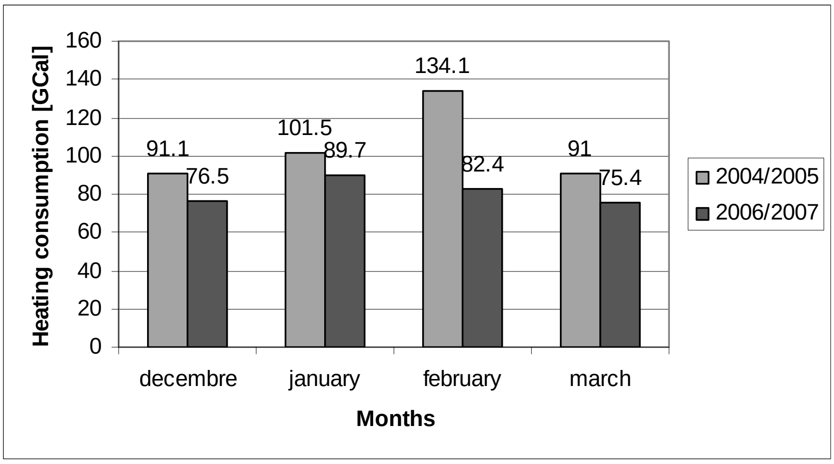


Figure 8. Variations of the heating consumption

The important reduction of the hot water consumption is due to the high efficiency of the thermal station, to the insulation of the distributions pipes and to the installation of timing taps in the shower cabinets. These timing faucets have actually led to a reduction of 40% of the hot water consumption in the whole building. Figure 8 shows the variations of the heating consumption, based on the real data gathered along two years of operation of the building.

As is shown in the Figure 8 the heating consumption during the winter decrease with 23% from the values registred before thermal reabilitation of hostel.

Taking into account the total amount of the termal reabilitation, that is about 110.000 Euros, and the economy achieved of 2100 Euros/month for heating and hot water, the value of the investment for the thermal rehabilitation is to be amortized in about 6 years. Figure 9 shows aspects of reabilitated hostel.

a. South facade reabilitated – general view

b. General view of student's room c. Aspects of bathroom

Figure 9. Aspects of the hostel's status after reabilitation

REFERENCES

C107/1-3/1007 - Romanian standard for the calculus of the global thermal insulation coefficients for the civil residences

D. Dan, S. Secula, V. Stoian – Technical project for reabilitation of C20, Campus Area Timişoara, Romania 2005

GT 036- 2002 - Guide for the thermal and energetic audit for the existing buildings and for the preparation for the hot water necessary for these buildings

GT 037- 2002 - Guide for the elaboration and assignment of the energetic certificate for the existing buildings

Existence and progress of deterioration of concrete facades

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ABSTRACT: Concrete structures exposed to outdoor climate are deteriorated by several different degradation mechanisms, whose existence and progress depend on many structural, exposure and material factors. Under Finnish outdoor climate the frost damage of concrete together with corrosion of reinforcing steel is the major degradation mechanism that causes the need to repair of concrete facades. During ongoing project *Service life of concrete facades – Existence and progress of deterioration*, it has been gathered the condition investigation data from about 700 buildings for now to a database. The database allows, for instance, reliable evaluation of the development of the condition, repair needs and repair market for concrete facades and balconies.

1 INTRODUCTION

1.1 *Back ground*

The value of Finnish buildings and infrastructure is about 300 billion euros (Technical R esearch Centre of Finland, Civil Engineering, 2001). Compared with the rest of Europe the Finnish building stock is quite young. Most of it has been built in the 1960's or later. The construction and real estate business accounts for more than 30 % of Finnish gross domestic product.

Since the 1960's a total of about 44 million square metres of concrete-panel facades have been built in Finland as well as almost a million concrete balconies (Vainio et al. 2005). Several problems have been encountered in their maintenance and repair. The structures have deteriorated due to several different degradation mechanisms whose progress depends on many structural, exposure and material factors. Thus, the service lives of structures vary widely. In some cases the structures have required, often unexpected, technically significant and costly repairs less than 10 years after their completion. For that reason, Finland has during the last 20 years developed many new methods for maintaining and repairing these structures. The methods include a condition investigation practice and its extensive utilization, rational repair methods and their selection as well as first-rate repair products and appropriate instructions for managing repair projects.

Concrete structures have been repaired extensively in Finland since early 1990s. During that almost 20 years period about 10 percent of the stock built in 1960-1980 has been repaired once. It is estimated that the total annual value of building repair work in Finland is about 5,500 million of euros, of which about 30 % involves external structures (walls, balconies, roofs, windows, etc.). The total annual volume of facade renovation is about 15 million m^2. In addition, 40,000 balconies are repaired annually and 4,500 new balconies are added to old buildings. It is estimated that the volume of facade renovation will grow 2 % annually (Vainio et al. 2005 and Vainio et al. 2002).

Because of great amount of those existing concrete structures, it is very important to solve their incident repair need economically and technically durable. This means, we have to use the most suitable repair methods for each case and it is also important to be able to determine the optimal time of those repairs.

1.2 *Objectives*

This paper is based on the authors' experiences from about 150 condition investigations of concrete structures, long-continued development of condition investigation systematics, and a ongoing project called *Service life of concrete facades – Existence and progress of deterioration.* The general objective of this research is to study the factors that have actually had an impact on the service life, existence and progress of deterioration in concrete facades and balconies. The three subgoals of the research are:

1. To find out the factors that have actually had an impact on the existence and progress of different deterioration mechanisms in concrete facades.
2. To find out the relative importance of said factors.
3. To provide new reliable data on the service-lives of concrete facades and balconies for use in calculational durability design and LCC-analyses of concrete structures.

The research project has started in March 2006 and it will continue until the end of March 2009.

2 ABOUT DEGRADATION MECHANISMS OF CONCRETE

The degradation of concrete structures with age is due primarily to weathering action which deteriorates material properties. Degradation may be unexpectedly quick if used materials or the work performance have been of poor quality or the structural solutions erroneous or non-performing. Weathering action may launch several parallel deterioration phenomena whereby a facade is degraded by the combined impact of several adverse phenomena. Degradation phenomena proceed slowly initially, but as the damage propagates, the rate of degradation generally increases.

The most common degradation mechanisms causing the need to repair concrete facades in Finland, and concrete structures in general, are corrosion of reinforcement due to carbonation or chlorides as well as insufficient frost resistance of concrete which leads to, for instance, frost damage (Pentti et al. 1998).

These degradation mechanisms may result in, for instance, reduced bearing capacity or bonding reliability of structures. Experience tells that defective performance of structural joints and connection details generally causes localised damage thereby accelerating local propagation of deterioration.

3 CONDITION INVESTIGATION

Damage to structures, its degree and extent, due to various degradation phenomena can be determined by a comprehensive systematic condition investigation. A condition investigation involves systematic determination of the condition and performance of a structural element or an aggregate of structural elements (e.g. a facade or balcony) and their repair need with respect to different degradation mechanisms by various research methods such as examining design documents, various field measurements and investigations and sampling and laboratory tests.

The wide variation in the states of degradation of buildings, and the fact that the most significant deterioration is not visible until it has progressed very far, necessitate thorough condition investigation at most concrete-structure repair sites. Evaluation of reinforcement corrosion and the degree of frost damage suffered by concrete are examples of such investigations.

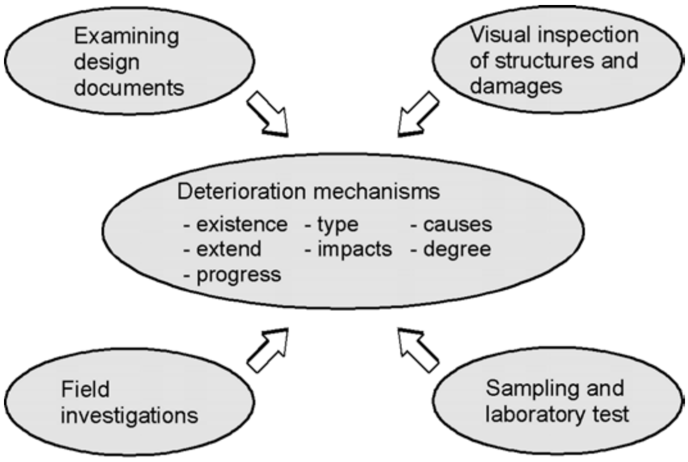

Figure 1. Different research methods in systematic condition investigation (Anon. 2002).

4 CREATING A DATABASE

Condition investigation systematics for concrete facades and balconies have been developed in Finland since the mid-1980s. A large body of data on implemented repair projects has been accumulated in the form of documents prepared in connection with condition investigations. About a thousand precast concrete apartment blocks have been subjected to a condition investigation, and painstakingly documented material on each one exists, including the buildings' structures and accurate reports on observed damage and need for repairs based on accurate field surveys and laboratory analyses.

During ongoing project *Service life of concrete facades – Existence and progress of deterioration*, it has been gathered the condition investigation data from about 700 buildings for now to a database. Those condition investigation reports has been collected from companies which have conducted such investigations as well as from property companies owned by cities. At this moment we have about 200 reports waiting for feeding into the database. In average each report includes investigation data from two buildings. This means, that in the end of summer 2007 the database will include the condition investigation data from about 1100 buildings.

4.1 *Distributions of buildings and structures*

Most of the blocks of flats stock in Finland is situated southern part of Finland. In the database those buildings has been divided in three different group based on their geographical position: coastal area, inland and North Finland. About thirds of those buildings are situated on coastal area and two-thirds on inland. Only few of buildings in the database is situated North Finland (see Fig. 2). This means we have to get more condition investigation reports from north.

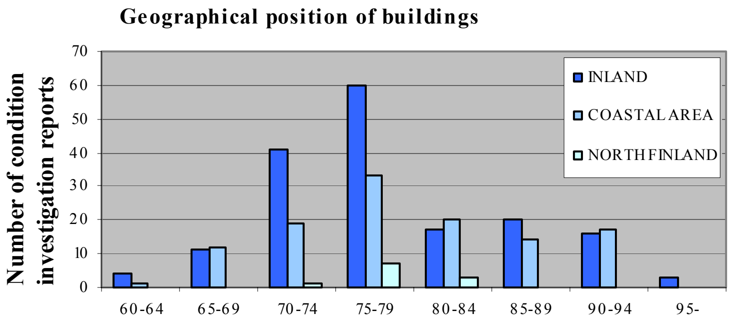

Figure 2. Geographical position of buildings in the database in five years period.

Prefabricated concrete facades have been the most common facade of residential buildings in Finland since late 1960s, at least in blocks of flats. A typical concrete element consists of an outer layer, thermal insulation (typically mineral wool) and an inner layer. The outer and inner layers are connected by trusses. The outer layer is typically 40 – 85 mm thick, and the strength of concrete is typically near C20. The thermal insulation is usually mineral wool with a design thickness of 70 – 140 mm. Due to the compaction of thermal insulation, the actual thickness is usually between 40 – 100 mm. The thickness of the inner layer is normally 150 – 160 mm (load bearing element) or 70 – 100 mm (non-load bearing elements).

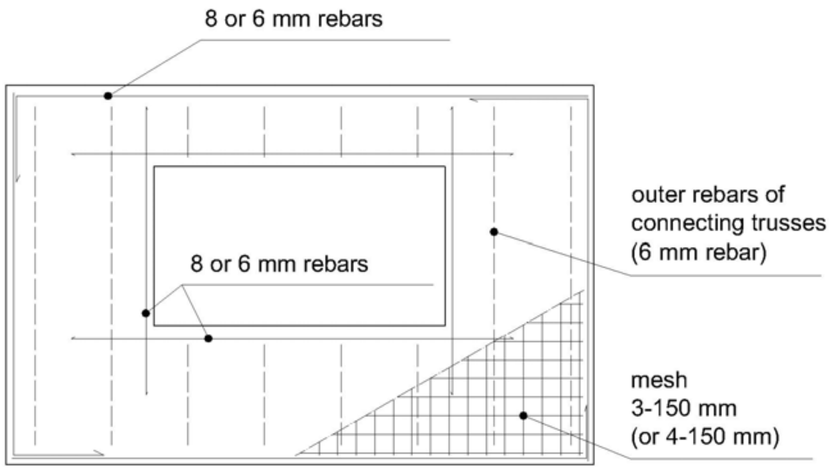

Figure 3. Typical outer layer of a Finnish concrete facade element.

Basically all prefabricated concrete panels has been made in the same way, but there is a lot of differences in their surface finishing and manufacturing. Those has a strong effect, for instance, on the situation of rebars and the quality of concrete. In the database the most common surface finishing are brushed and painted concrete, exposed aggregate concrete and painted plain concrete. The distributions of surface finishing on the database is shown in Fig. 4.

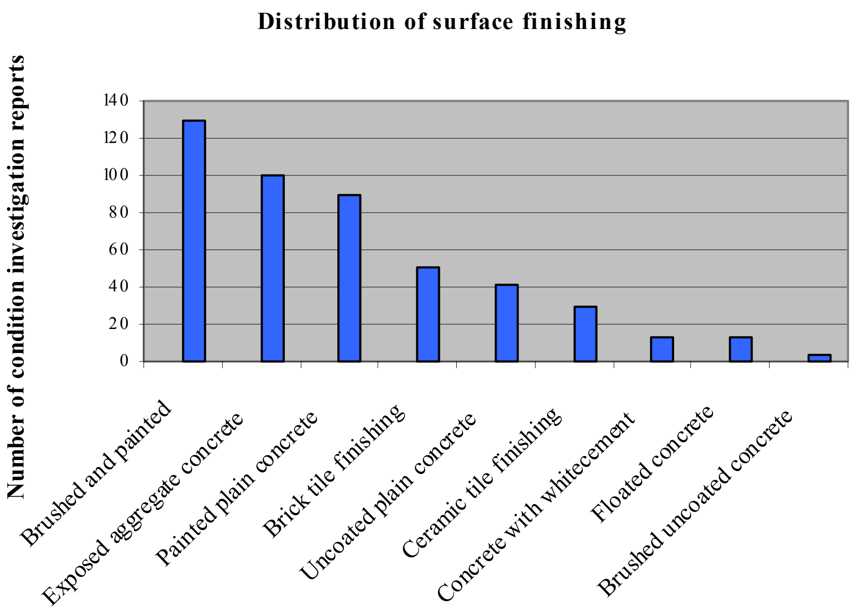

Figure 4. Distribution of surface finishing in the database.

The most common type of balcony from late 1960s in Finland consist on frame, slab and parapet elements which are prefabricated from concrete. Those balcony elements consist so called balcony-tower, which has own foundations and the whole tower has been connected to buildings frame only for horizontal loads.

5 EXECUTION OF THE RESEARCH

5.1 *Corrosion of steel*

Reinforcing bars in concrete are normally well protected from corrosion due to the high alkalinity of the concrete pore water. Corrosion may start when the passivity is destroyed, either by chloride penetration or due to the lowering of the pH in the carbonated concrete. Steel corrosion in carbonated concrete or in chloride migrated concrete has been widely studied (Tuutti 1982, Parrott 1987, Schiessl 1994, Richardson 1988, Broomfield 1997, Mattila 2003 etc.).

In condition investigation reports there is a lot of measured data concerning corrosion of steel in concrete. This data consist on several measurements of cover depth of steelbars, carbonation of concrete, chloride migration in concrete, quality of concrete (porosity, comprehensive strength), size and amount of reinforcement, dimensions of structures and structure members etc.

In written mode is also a lot of qualitative information on direction and heights of sampling points, situation of building (coastal area, inland), high or low building, amount of visible corrosion damages, type of facades surface (exposed aggregate concrete, brushed and painted concrete, painted plain concrete etc.) etc. This data together with measurements tells actual effects of outdoor climate on different concrete facades.

5.2 *Active corrosion*

Once the passivity is destroyed either by carbonation or by chloride contamination, active corrosion may start in the presence of moisture and oxygen (Parrott 1987). Corrosion may run for a long time before it can be noticed on the surface of the structure. Because corrosion products are not water soluble, they accumulate on the surface of steel nearby he anodic area (Mattila 1995). This generates an internal pressure, because the volume of the corrosion products induced by carbonation is four to six times bigger than original steelbars (Tuutti 1982).

Internal pressure caused by corrosion products leads to cracking or spalling of the concrete cover. Visible damage appears first on the spots where the concrete cover is smallest.

Comparing the quantity and stage of damage of steelbars in corrosion state and their cover and carbonation depths to visible corrosion damages, it is possible to estimate the actual time for active corrosion in different Finnish climatic conditions.

5.3 *Disintegration of concrete*

Concrete is a very brittle material. It can stand only extremely limited tensile strains without cracking. Internal tensile stresses due to expansion processes inside concrete may result in internal cracking and, therefore, disintegration of concrete. Disintegration of concrete accelerates carbonation and this way also steel corrosion. Concrete may disintegrate as a result several phenomenon causing internal expansion, such as frost weathering, formation of late ettringite or alkali-aggregate reaction.

5.4 *Frost resistance of corrosion*

Concrete is a porous material whose pore system may, depending on the conditions, hold varying amounts of water. As the water in the pore system freezes, it expands about 9 % by volume which creates hydraulic pressure in the system (Pigeon and Pleau 1995). If the level of water saturation of the system is high, the overpressure cannot escape into air-filled pores and thus damages the internal structure of the concrete resulting in its degradation. Far advanced frost damage leads to total loss of concrete strength.

The frost resistance of concrete can be ensured by air-entraining which creates a sufficient amount of permanently air-filled so-called protective pores where the pressure from the freezing dilation of water can escape. Finnish guidelines for the air-entraining of facade concrete mixes were issued in 1976 (Anon. 2002).

Moisture behaviour and environmental stress conditions have an impact on frost stress. For instance, the stress on balcony structures depends on the existence of proper waterproofing.

In condition investigation reports there is a lot of measured data concerning frost resistance of concrete or frost damages in concrete. This data consist on several measurements of quality of concrete (porosity, comprehensive strength), protective porosity of concrete, tensile strength of concrete, thickness of insulation layer etc.

In written mode is also a lot of qualitative information on thin-section analysis, moisture behaviour, coatings and amount of visible frost damages etc. in addition to mentioned before.

5.5 *Statistical studies*

The data from the condition investigations will be used to determine how various factors (structural, exposure and material factors) have contributed to the existence of damage and the rate of its advancement as well as the relative importance of the factors.

A large group of buildings that has been subject to actual climatic stress for a long time provides valuable indication on the advancement of deterioration when constructing models to predict the service life of, for instance, new structures and in defining their parameters. Such material provides data on many parameters influencing the advancement of deterioration, such as quality of concrete, dimensions of structures, surface materials and treatments as well as environmental conditions. It will also be interesting to discover the relationship between the amount of visible damage and the actual state of deterioration and how closely the data derived by different condition investigation methods correspond.

5.6 *Other studies*

Codes and instructions in building as well as concrete and cement standards have been changed a lot since 1960’s. The present-day cement is much more fine-grained and the compressive strength of concrete has increased from C20 to C35 or higher. In this research it will be studied how those factors influence deterioration of structures.

General economical situation has a strong influence on the amount of buildings which are under construction in a certain time. During an upward economical trend there is a lot of buildings under construction and both constructors and precast element factories are overbooked. It is interesting to discover if this has any influence on the general quality of precast concrete elements and their deterioration.

5.7 *Service-life models*

In most of the present service-life models the limit state determining the theoretical end of the service-life is considered to be the initiation of corrosion or frost damage. Models for service-live calculations have been prepared by Bob 1996, Lindvall 1998, Maage et al. 1996, Parrot 1994, Vesikari 1988 and 1998. Those models are made for new structures, not for old and already deteriorated structures.

The present service-life models will be evaluated critically based on received results of this research.

5.8 *Evaluating different condition investigation methods*

Research data produced by different measurement and investigation methods will be compared and evaluated. The present Finnish guidance for condition investigation methods will be evaluated too. The condition investigation practices and experiences of European countries will be looked into.

6 EXPECTED RESULTS

The research will produce at least the following benefits:

- a more clear and reliable assessment of the condition and renovation need of the existing concrete facade and balcony stock as well as their future development
- new data on deterioration of concrete structures and the factors affecting it under actual natural conditions
- new data on the applicability and reliability of different condition investigation methods.

6.1 *Utilization of research results*

The statistical data on the progress of deterioration collected and analyzed in this research are needed in forecasting future repair needs on a national scale in Finland. In addition, the data can be made use of, for instance, in the development of residential neighbourhoods and financial planning by large property owners as well as in planning the operations of companies involved in the repair sector. The data can also be used to identify the factors contributing to deterioration. Discovered causal relationships in practical conditions are necessary for assessing and creating theoretical models for the design and evaluation of the service life of concrete structures.

The data may also be used in the development of condition investigation methods by, for instance, comparing the reliability of different measurement methods representing various indicators of deterioration. The resources available for condition investigations are usually limited which is why they are made with the sampling method, which always involves a factor of uncertainty. On the basis of this research, the resources invested in condition investigations can be targeted more accurately on critical structures, mechanisms and parameters of deterioration which, again, will improve remarkably the accuracy and reliability of condition investigations.

REFERENCES

Anon. 2002: Condition investigation manual for concrete facade panels. Helsinki. Concrete Association of Finland BY 42 178 p. (In Finnish)

Bob C. 1996: Probabilistic assessment of reinforcement corrosion in existing structures. Dhir, R.K. and Jones, M.R. (editors). Concrete repair, rehabilitation and protection. Suffolk. E & FN Spon. Pp. 17-28

Broomfield J. 1997: Corrosion of steel in concrete – understanding, investigation and repair. London. E & FN Spon. 240 p.

Lindvall A. 1998: Duracrete – Probabilistic performance based durability design of concrete structures. Proceedings of 2nd international PhD symposium in civil engineering. Budapest.

Maage M., Helland S., Poulsen E., Vennesland Ö. and Carlsen J.E. 1996: Service life prediction of existing concrete structures exposed to marine environment. ACI Materials Journal, Nov.-Dec. Pp 602-608.

Mattila J. 1995: Realkalisation of concrete by cement-based coatings. Tampere, Tampere University of Technology, Structural Engineering. Licentiate´s Thesis. 161 p. (In Finnish)

Mattila J. 2003: On the durability of cement-based patch repairs on Finnish concrete facades and balconies. Tampere, Tampere University of Technology, Publication 450. 111 p.

Parrott L.J. 1987: Review of carbonation in reinforced concrete. Cement and Concrete Association. Wexham Springs. 42 p.

Parrot P.J. 1994: Design for avoiding damage due to carbonation-induced corrosion. Malhotra, V.M- (editor). Durability of concrete. Detroit. American Concrete Institute. Pp. 283-298.

Pigeon M., Pleau R.1995: Durability of Concrete in Cold Climates. Suffolk. E & FN Spon. 244 p.

Pentti Matti, Mattila Jussi, Wahlman Jyrki 1998: Repair of concrete facades and balconies, part I: structures, degradation and condition investigation. Tampere, Tampere University of Technology, Structural Engineering. Publication 87. 157 p. (In Finnish)

Richardson M. 1988: Carbonation of reinforced concrete. Dublin, CITIS. 203 p.

Schiessl P, Breit W, Raupach M. 1994: Durability of local repair measures on concrete structures damaged by reinforcement corrosion. Mathora, V.M- (editor). Durability of concrete. Detroit. American Concrete Institute. Pp. 1195-1215

Tuutti K. 1982: *Corrosion of Steel in Concrete*. Stockholm. Swedish Cement and Concrete Research Institute. CBI Research 4:82. 304 p.

Vainio et al. 2002: Korjausrakentaminen 2000‒2010 [Repair, maintenance and improvement work in Finland]. Espoo 2002. VTT Research Notes 2154. 60 p. + app. 25 p. (In Finnish)

Vainio et al. 2005: Julkisivujen uudis- ja korjausrakentaminen. Tampere, 2005. VTT 26 p. + app. 13 (In Finnish)
Vesikari E. 1988: Service life of concrete structures with regard to corrosion of reinforcement. VTT research reports. Espoo. 53 p.
Vesikari E. 1998: Evaluation of service-life of concrete structures by computer simulation. VTT Building technology. Research report RTE30275/98. 36 p.

Environmental assessment of the maintenance of façade openings in dwellings – the Dutch case

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ABSTRACT

In this paper, some environmental aspects of the maintenance of Dutch residential buildings are assessed quantitatively. The emphasis is on existing buildings, built by traditional Dutch building methods. Since there is no assessment method readily available to assess maintenance scenarios, an environmental assessment method has been developed based on existing environmental assessment methods, such as life cycle assessment (LCA). The aim of performing the assessments is threefold: they are used to further develop the assessment method for residential building maintenance in an iterative way; they are used to distinguish the type of environmental problems that building maintenance contributes to; and the factors that have the highest potential for improvement of the environmental performance of maintaining a building are identified. The development of the assessment method includes determining which activities should be taken into account, either because they occur frequently or because they are expected to cause a relatively high environmental impact.

1 INTRODUCTION

Environmental impacts related to residential buildings cover a large part of the total annual environmental impact in the Netherlands. Each year, about 65,000 new dwellings get built (CBS 2006), which requires material and energy resources. The building parts need to be produced and transported, which causes waste and emissions to the environment. About 13,500 dwellings get demolished on a yearly basis (CBS 2006), which produces a lot of waste that needs to be processed. Another 6.9 million dwellings are in use (CBS 2006). These dwellings continuously require energy to provide a comfortable indoor climate, and they need to be maintained and adapted to changing needs of occupants.

The focus of research in the field of environmental assessment of buildings thus far has been on the use of resources in the construction phase, the use of energy for climate control in the operational phase of a building, and waste processing after demolition. In the Netherlands, three quarters of the existing residential building stock is less than 50 years old. At the current renewal rate of about 0.25% per year (Thomsen 2006), the existing stock is here to stay for another 350 years on average.

The existing residential building stock is an important factor to look at in an attempt to reduce the annual environmental impact associated with residential buildings, because on a yearly basis, the environmental impact caused by living in and maintaining residential buildings in the Netherlands might be bigger than the impact caused by building and demolishing residential buildings. During the use phase of a building, environmental impact occurs because of the use of energy for climate control and other activities, the maintenance of the building and building services, and replacement of interior finishing.

In this paper, the focus is on the quantitative environmental assessment of the maintenance of residential buildings in the Netherlands. Maintenance will lead to environmental impact because of the use of materials and energy that is needed to perform maintenance. However, maintenance will also help postpone or prevent other activities, such as replacement of building parts and demolition of the building. It is therefore not sufficient to assess maintenance activities separately. Maintenance activities should be assessed in relation to each other and other processes that they influence. This is why in this research maintenance scenarios are assessed, in which multiple activities and processes are included.

Environmental assessment methods combine several aspects. In section 2, the basis for the assessment method, the set of indicators and the corresponding calculation methods are dealt with. The object of the assessment, which determines part of the environmental assessment method, is explained in section 3. Section 4 contains two comparative calculations: the comparison between the environmental impact caused by maintenance to façade openings and the environmental impact caused by the production of the façade; and a comparison between the environmental impact caused by the production of high thermal insulation glazing and the environmental impact caused by energy for space heating. Finally, in section 5, the calculations are discussed and conclusions for further research are drawn.

2 ENVIRONMENTAL ASSESSMENT

A quantitative environmental assessment method is the calculation of the (potential) contribution of an object to predefined environmental problems and the analysis of the results. The object of the assessment can be a product or a process. There is not one single quantitative environmental assessment method that can be used for any kind of object. The specific combination of the object, the type of results needed, the set of predefined environmental problems and the corresponding calculation methods leads to an environmental assessment method for a specific goal. In this research, the environmental assessment method is based on existing methods, which will be explained in this section. The object of the assessment is maintenance of residential building, which is further explained in section 3.

Quantitative environmental assessment methods are based on an inventory of material and energy flows that occur during the production, use and disposal of a product. The basis of these methods is the closed mass and energy balance: all natural resources that are needed to produce a product will eventually be discharged to the environment. There are two levels at which quantitative methods operate: at the level of bulk material and energy flows and at the far more detailed level of individual substance flows (Daniels & Moore 2002). Methods operating on the first level are based on the idea that the source of environmental problems is the volume of material and energy flows, which means that smaller flows are better. Tools that operate on the second level also look at the effect or the impact that substance flows have on the environment. In the impact assessment, the potential contribution of the flows to specific environmental problems is determined. This quantitative assessment method is known as life cycle assessment (LCA). At this level, the quality of material and energy flows are taken into account as well, which allows for choosing between different kinds of material and energy.

Life Cycle Assessment is the basis of the environmental assessment method developed for this research. Because of the many ways LCA can be used and the growing number of environmental effects that are taken into account, an international standard for LCA has been developed: the ISO 14040 series. The standard describes the four steps that have to be taken in a life cycle assessment (Fig. 1). The ISO-standards merely pose the components that an LCA study should contain, but the way the assessment is conducted depends on the goal and scope of the assessment. This means that only LCA studies with the same goal and scope can be compared, because the way in which the assessment is conducted will be defined by it. The goal and scope definition also contain the questions that the results of the assessment should answer and the indicators that are used to describe the environmental performance of the assessment object.

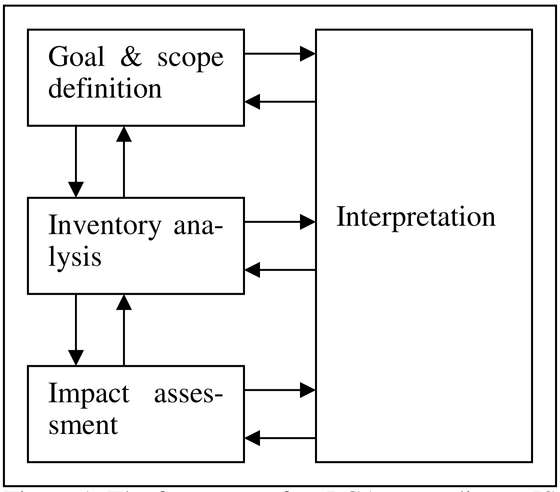

Figure 1. The four steps of an LCA, according to ISO 14040.

There are basically two ways to define indicators for environmental performance (Blom 2005; Guinée 2002; Heijungs et al. 2003). The first is a top-down method, which is based on the information that is needed in order to make decisions. The indicators describe the final effects on human health and ecosystems, such as the years of (healthy) life lost or the loss of biodiversity. These effects are situated at the end of the chain of causes and effects, which is why they are called endpoint effects. Most of these effects cannot exactly be determined, because there are some assumptions about causes and effects that cannot be verified yet. The second type of indicators is based on information that is available and can be verified. There are some trends in the environment of which the cause is known. For example, the depletion of the ozone layer is caused by the presence of substances in the stratosphere that decompose ozone molecules. The amount of these substances that is emitted to the air can be calculated. The potential ability to decompose ozone molecules is a midpoint effect. Depletion of the ozone layer will be the cause of other effects, such as more cases of skin cancer, which cannot be calculated yet. In this research, the midpoint indicator set that is described in the CML method will be used (Guinée 2002). The indicators are: abiotic resource depletion, greenhouse effect, depletion of the ozone layer, photochemical oxidation (smog), human toxicity, fresh water ecotoxicity, terrestrial ecotoxicity, eutrophication and acidification.

3 MAINTENANCE SCENARIOS

In this research, maintenance is defined as activities that are aimed at maintaining a certain performance level of the building parts and stretching the service life of both building parts and the building itself as much as possible. The activities include protecting building parts from deteriorating and keeping the protection intact. It also includes replacing parts of the building that no longer function or that could function better. Traditionally, the definition of maintenance does not include activities that result in a higher or different performance level than the original performance level of the building or component (Straub 2001; Vijverberg 1991). However, the required performance level of buildings and building parts by regulations and demand changes. Therefore the upgrading of the performance level of buildings and components by replacing with higher quality products is also taken into account. At times, replacing a building part with a higher quality part leads to changes in the use of buildings. For example, when glazing is replaced by glazing with a higher thermal resistance, the loss of energy will be less. Thus, less energy is needed to heat the dwelling.

The focus of this paper is on maintenance of façade openings (windows and doors) of existing houses. First, a comparison is made between the environmental effects of maintaining façade openings and the environmental effects embodied in the façade itself (materials). This way, we'll be able to make a raw estimate of the environmental significance of maintenance activities compared to construction activities. Additionally, a raw estimate of the significance of maintenance at the building stock level can be made.

Second, the effect of replacing the existing double glazing by high thermal insulation glazing will be studied. The environmental effects of the annual energy use for space heating are taken into account, which will decrease after the replacement of the glazing.

4 CALCULATIONS AND RESULTS

4.1 *Calculation method*

The calculations consist of summing up the environmental profiles of the materials and processes used in the maintenance scenarios. An environmental profile consists of the contribution of a unit of the material or process to the 9 environmental effects mentioned before. The environmental profiles used are taken from the *EcoQuantum 2.0* database, unless indicated otherwise. The results of the environmental impact of products, activities and scenarios are displayed on a year by year basis, cumulative, according to the method described in (Itard and Klunder, 2007a and Itard 2007b).

In the case of the replacement of double glazing, the time it takes for each environmental impact of the replacement to be 'paid-back' by the environmental impact saved because of the reduction in energy use for space heating is calculated. To do this, for each environmental effect the difference in annual impact by energy use between both glazing types is divided by the impact of the production of thermal insulation glazing.

4.2 *Effect of maintenance of façade openings relative to the façade*

4.2.1 *Assumptions*

First, the environmental impact caused by maintaining façade openings for 50 years is compared with the environmental impact of producing the entire façade. Table 1 shows the façade components taken into account. The components and their measurements are taken from a Dutch single-family reference dwelling ('tussenwoning'), as described in (Novem 2001). The service life is taken from *EcoQuantum 2.0*.

Table 1. Façade components and service life in the reference building.

Façade components	Service life [years]	Amount
Brickwork		69.8 m^2
Insulation (rock wool)		53.1 m^2
Load-bearing wall		53.1 m^2
Timber window and door frames*	50 (paint: 35)	23.3 / 5.5 m^2 (fixed / opening)
Door and window furniture (hinges, locks)*	20	
Doors*	40	3
Glazing*	double glazing: 25 (sealant: 15)	0.8 / 18.3 m^2 (single/double)
Ventilation grille		3.5 m
Windowsill		13.2 m
Concrete beams		15.2 m
Water barrier		23.8 / 18 m (ldpe / lead)

Components marked with * are maintained and / or replaced in the 50 year scenario.

In the maintenance scenario, the following activities are taken into account:

- applying a new layer of paint on timber parts: every 6 years;
- removing old paint layers and applying a new base layer: after 35 years (starting a new cycle of 6 years);

- replacing glazing sealant: every 15 years;
- replacing double glazing: after 25 years;
- replacing door furniture (hinges and locks): after 20 years;
- replacing doors: after 40 years.

4.2.2 *Results*

In Table 2, the results of the calculations are listed. For each environmental effect, the contribution of maintenance activities is related to the contribution of producing the entire façade.

Table 2. The contribution of maintenance to the environmental effects, related to the production of the entire façade.

Environmental effect	Relative contribution of maintenance [%]
Human toxicity	5
Terrestrial ecotoxicity	10
Ozone layer depletion	12
Eutrophication	15
Ecotoxicity fresh water	18
Photochemical oxidation	19
Greenhouse effect	20
Acidification	22
Abiotic depletion	43

The results of the calculations are for a 50 year scenario. The service life of buildings will be longer than 50 years, at least 200 years if the current renewal rate of dwellings would double in the Netherlands. Therefore, the environmental impact of maintenance during the entire service life of the building will be higher than the calculated contribution.

When looking at the entire building stock in the Netherlands, which contains 6.9 million dwellings and to which about 65,000 dwellings are added annually, the environmental impact by maintenance in relation to the production of new façades can be estimated as follows. The environmental impact of producing a façade for one dwelling is indexed at 100. If the environmental impact of maintenance is 20% of the impact of the façade after 50 years, like the contribution to the greenhouse effect, than the annual index for the maintenance of one façade is 20/50. The façade index is multiplied by the amount of new dwellings per year, and the maintenance index is multiplied by the total amount of dwellings in the Netherlands. In this case, the environmental impact by maintenance is about 40% of the impact caused by producing new façades.

4.3 *Effect of replacing double glazing by high thermal insulation glazing*

4.3.1 *Assumptions*

A comparison is made between two scenarios of 25 years:
- Scenario A: no replacement of the existing double glazing, annual energy use for space heating.
- Scenario B: replacement of double glazing by high thermal insulation glazing in year 1, annual energy use for space heating.

In scenario B, only the production of the high thermal insulation glazing is taken into account. The environmental impact of the waste processing of the removed double glazing is not taken into account, because the waste of the double glazing was already going to happen, no matter if the new glazing is being put in or not. In this research, only additional environmental impact by maintenance and replacements to the impact of the existing building is taken into account. The waste that is produced when the new high thermal insulation glazing is eventually removed or replaced will be taken into account.

Table 3: calculation values for scenario A and B.

	Scenario A	Scenario B
U-value glazing	2.6 W/m^2K	1.8 W/m^2K

Glazing area	18.3 m^2	18.3 m^2
Energy use for space heating (natural gas)	24847 MJ/year	20475 MJ/year

The environmental profile of high thermal insulation glazing is not available in *EcoQuantum 2.0*. The profile was therefore calculated in *SimaPro 7.0*, using the same CML baseline method as used for the environmental profiles of *EcoQuantum 2.0*. One square meter of high thermal insulation glazing consists of:

- 10 kg of coated glass (4 mm thick);
- 12.5 kg of uncoated glass (5 mm thick);
- 0.449 kg of aluminium spacer;
- 0.000025 kg of silicone product.

All data is from the *ecoinvent 1.2* database. Not included in this study are the steel part of the spacer, the outer profile of PE and the argon gas in the cavity.

4.3.2 *Results*

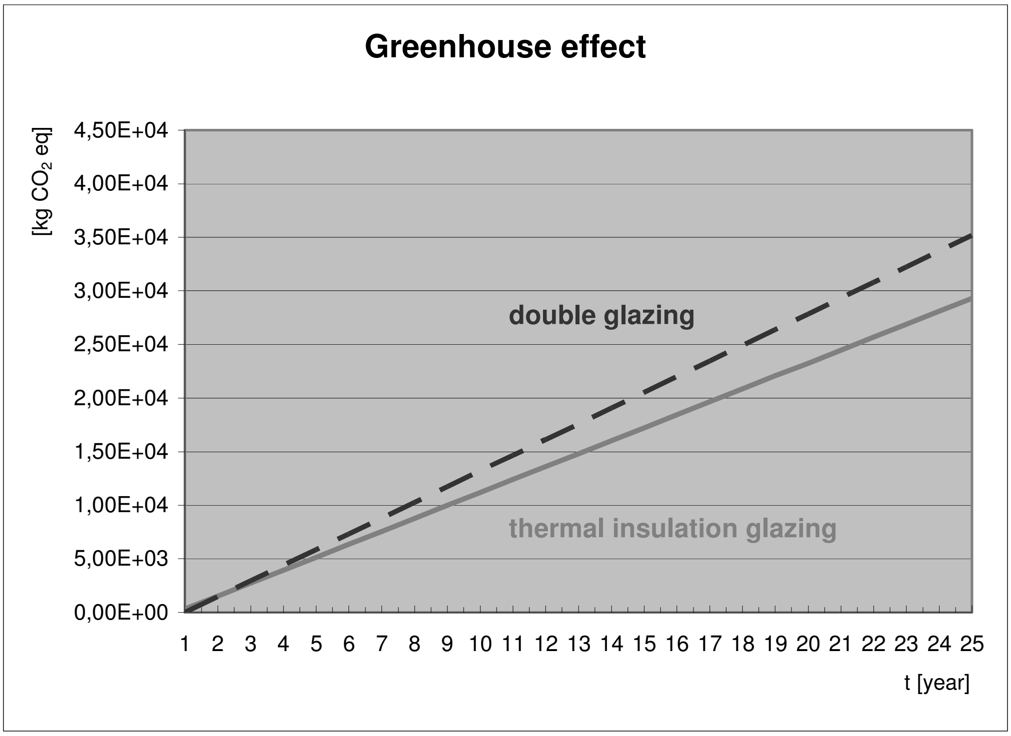

Figure 2. Replacing glazing has an immediate impact on the greenhouse effect.

For both abiotic depletion and the greenhouse effect, replacing the glazing has an immediate positive effect on the annual environmental impact. This is because energy use has a big impact on those environmental effects. For photochemical oxidation and terrestrial ecotoxicity, the production of high thermal insulation glazing has a positive effect after 14 years. For all other effects, the pay-back time is more than 25 years (see Table 4). Especially the human toxicity and ecotoxicity fresh water have long pay-back times, which are caused by the coating used on the thermal insulation glazing. The coating consists of metal ions, which contribute considerably to the two effects mentioned.

Table 4. Pay-back time of high thermal insulation glazing and amount of environmental impact.

Environmental effect	Pay-back time for high thermal insulation glazing [years]	Contribution to effect 'saved' after 25 years [%]
Abiotic depletion	1	401
Greenhouse effect	2	18.6

Eutrophication	14	0.79
Photochemical oxidation	14	0.61
Terrestrial ecotoxicity	26	-0.06
Ozone layer depletion	59	-0.59
Acidification	96	-0.75
Ecotoxicity fresh water	170	-0.86
Human toxicity	214	-0.89

High thermal insulation glazing has been developed to reduce the depletion of energy resources and CO_2 emissions, which is effective. The amount of abiotic resources used for the high thermal insulation glazing is low compared with the annual amount of abiotic resources needed for space heating. After 25 years, 400 times the input of abiotic resources for the high thermal insulation glazing is saved by the reduced energy use for space heating. The same reasoning is valid for the greenhouse effect, though the reduction after 25 years is only 18.6% of the amount of CO_2 equivalents emitted for the production of the high thermal insulation glazing. For the other 7 effects, the environmental effects saved after 25 years are low, because these effects are hardly influenced by energy for space heating.

5 DISCUSSION AND CONCLUSIONS

At the façade level, the environmental impact of 50 years of maintenance compared to the impact of producing the façade ranges from 5 to 43%. When the entire service life of the building – which is at least 200 years in the Netherlands at the current renewal rate – is taken into account, the relative impact will be more. Moreover, if the annual environmental impact of maintaining the entire residential building stock of 6.9 million dwellings is compared with the production of about 65,000 new facades per year, reducing the environmental impact of maintenance will contribute to the reduction of the annual environmental impact of buildings in the Netherlands.

In the continuation of the research, other activities that are related to maintenance will be taken into account. For example, the influence of transport related to maintenance activities will be taken into account. Additionally, activities that do not require any other materials and processes than transport, such as inspection of the building to assess the need for maintenance, will be taken into account. Inspections are needed if a just-in-time policy is adopted, in which maintenance activities are not performed until they are actually needed instead of when they are planned. More comparisons between complete maintenance scenarios will be made. In order to calculate the environmental impact of complete maintenance scenarios, additional data needs to be assembled on both the materials and processes level, and at the activity level.

The questions for further research are:

- What is the relation between the environmental impact by maintenance activities and the prevented environmental impact in the building service life, when the performance level of the building is kept constant?
- Does this relation change when higher quality products are used to replace building parts?
- What is the pay-back time for higher-quality products in terms of environmental impact?
- At the level of the building stock, what is the contribution of maintenance to the total annual environmental impact in the Netherlands in relation to other environmental impact related to residential buildings?

REFERENCES

Blom, IS 2005, 'Aanzet tot een nieuw LCA-model voor gebouwen', Technische Universiteit Eindhoven.

CBS 2006, *Woningvoorraad naar bouwjaar*, Voorburg/Heerlen.

Daniels, PL & Moore, S 2002, 'Approaches for Quantifying the Metabolism of Physical Economies. Part I: Methodological Overview', *Journal of Industrial Ecology*, vol. 5, no. 4, pp. 69-93.

Guinée, JB 2002, *Handbook on Life Cycle Assessment - Operational Guide to the ISO Standards*, Eco-efficiency in Industry and Science, Kluwer Academic Publishers, Dordrecht.

Heijungs, R, Goedkoop, M, Struijs, J, Effting, S, Sevenster, M & Huppers, G 2003, *Towards a life cycle impact assessment method which comprises category indicators at the midpoint and the endpoint level - Report of the first project phase: Design of the new method*, Pré Consultants, Amersfoort.

Itard, L., Klunder G. 2007, *Comparing Environmental Impacts of Renovated Housing Stock to New Construction,* Building Research and Information, Vol. 35, Issue 3, pp.252-267

Itard, L. 2007 *Milieueffecten van renovatie-ingrepen in de woningvoorraad, Habiforum report*, www.otb.tudelft.nl

Novem 2001, *Referentiewoningen bestaande bouw*, 1DUWO01.01, Novem, Sittard.

Straub, A 2001, *Technisch beheer door woningcorporaties in de 21e eeuw - Professioneel, klantgericht en duurzaam*, vol. 21, Bouwmanagement en Technisch Beheer, DUP Science, Delft.

Thomsen, A 2006, *Levensloop - van woningen -*, Technische Universiteit Delft, Delft.

Vijverberg, G 1991, *Planning van bouwkundig onderhoud aan schoolgebouwen - Oriëntering, modellering, institutionalisering*, vol. 3, Bouwmanagement en Technisch Beheer, Delftse Universitaire Pers, Delft.

How sustainable rehabilitation designers really are

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ABSTRACT: RE-ARCHITECTURE is a design process support system that aims to support designers, when involved in rehabilitation design developments. Before getting access to the full content of RE-ARCHITECTURE, users were asked to contribute to a pre-survey, by answering online Questionnaire B1. The analysis of its results, intended to identify the category of designers, their design processes and guiding principles. As RE-ARCHITECTURE aims to contribute to a more sustained and lifespan conscious rehabilitation design development, this pre-survey is fundamental to understand how sustainable rehabilitation designers really are and how appropriate RE-ARCHITECTURE can be to sustain their aims. This paper synthesizes the pre-survey results, where such issues were most evident.

1 INTRODUCTION

RE-ARCHITECTURE is a design process support system that aims to support designers, when involved in rehabilitation design developments of one or more buildings, dated of more than one generation old. RE-ARCHITECTURE provides free and fast access to a wide range of technical sustenance - knowledge and tools - for the different stages, sub-stages and activities, common in such design processes.

Rehabilitation design developments are usually complex, in the sense that the designer has to deal with a pre-existence that should not be neglected or predominantly be destroyed. Otherwise, such intervention should no longer be called building rehabilitation. Eventually, it could be called urban rehabilitation or, even more specifically e.g. reuse of structural elements.

RE-ARCHITECTURE is the implementation of the design process theorised in the doctoral research *RE-ARCHITECTURE: lifespan rehabilitation of built heritage*; hosted at the Faculty of Architecture, Building and Planning, Eindhoven University of Technology (TU/e), The Netherlands; and funded by the Foundation for Science and Technology, Portugal since 2004.

2 METHOD

This research has now come to the test period, where designers - architects and architecture students - from the Netherlands and Portugal, with experience in rehabilitation design developments, were invited to register and get free access to RE-ARCHITECTURE, for a period of four months. As public invitation, some articles and short news items were published in both countries (paper and web-based). Among others, the Royal Association of Dutch Architects and the Portuguese Order of Architects were most cooperative. Several e-mails were also sent to those designers who had previously shown interest in RE-ARCHITECTURE.

After registering as a new user and before getting access to the full content of RE-ARCHITECTURE, users were asked to contribute to a pre-survey, by answering online Questionnaire B1. Then, their workflow was controlled through process mining techniques (Alves de Medeiros, 2006), researched at the Faculty of Technology Management, TU/e. In the end, they were asked to fill in a post-survey.

The pre-survey comprised a group of forty five questions; nineteen main questions and twenty six sub-questions. The analysis of its results, intended to identify the design processes and guiding principles of the designers, before being exposed to RE-ARCHITECTURE. It was fundamental to understand how sustainable rehabilitation designers really are.

Together with the post-survey, the pre-survey was essential to achieve accurate results and conclusions at the end of this research. Both surveys reveal the effective role and/or contribution of RE-ARCHITECTURE, as a support system that was proposed to support designers raising their lifespan consciousness in their rehabilitation design processes and the consequent sustainability of their designs.

3 RESULTS

3.1 *The sample*

The universe of RE-ARCHITECTURE users, was limited to those who simultaneously registered before April 1st, 2007 and submitted entries in the Pre-survey system (N_t=408). Among this universe, three categories of users were identified (Table 1): first, who filled in the Pre-survey accurately (complete, valid); second, who did not fill in the Pre-survey accurately (complete, invalid); and third, who did not complete the Pre-survey (incomplete).

Table 1. The universe of RE-ARCHITECTURE users

	Architects				Architecture students				Other occupations				Total
	CV	CI	I	***N*a**	CV	CI	I	***N*s**	CV	CI	I	***N*o**	***N*t**
Portugal	79	14	110	**203**	20	2	15	**37**	12	19	24	**55**	**295**
The Netherlands	25	5	30	**60**	27	3	2	**32**	2	2	1	**5**	**97**
Other countries	-	2	6	**8**	-	-	-	-	2	2	4	**8**	**16**
	104	21	146	**271**	47	5	17	**69**	16	23	29	**68**	**408**

*CV = Complete, Valid; CI = Complete, Invalid; I = Incomplete; *N* = Universe (total number)

The following chapters synthesize the answers of the RE-ARCHITECTURE users, who filled in the Pre-survey accurately. Moreover, it groups the users according to two fundamental variables; the country (values: Portugal, The Netherlands and other countries) and the occupation (values: architect, architecture student and other occupations). As this research aims to survey Portugal and The Netherlands; as well as, architects and architecture students only; the answers of the other users were left out of consideration.

Due to the fact that the variables and values differed in number of users; a sample was taken to enable accurate comparisons and disable deviation of results, when correlating the answers. The total number of architecture students (*N*pt/s=20), registered from Portugal – the smallest – was the limiting value for the sample of users (Table 1).

Therefore, a sample of twenty users was also selected from the other three groups (*N*pt/a; *N*nl/s; *N*nl/a). The rule was to select the first twenty users, independent from the quality of their answers. In total, the surveyed sample represents a universe of eighty users (*N*t=80). They characterize approximately twenty percent (20%) of the surveyed universe of users; and, forty-eight percent (48%) of the total number of users that have completed the pre-survey accurately.

The following chapters characterize this sample on four aspects: experience in developing rehabilitation designs (see section 3.2); interest of developing rehabilitation designs (see section 3.3); aims towards the building subtractions, remainings and additions (see section 3.4); as well as, percentual relation (see section 3.5). In order to effectively reveal the survey results that would indicate how sustainable rehabilitation designers really are; the researcher has selected some particular survey results for this paper.

3.2 *The experience in developing rehabilitation designs*

As already expected, fifty-two users (65%) confirmed their previous experience in developing rehabilitation designs. Unexpectedly, twenty-eight (35%) affirmed to have never developed a rehabilitation design. Either, because it is really true or because the users were just trying to make a shortcut and access faster the RE-ARCHITECTURE content; fact is that, this percentage of inexperienced users clearly reflects the current reality and sustains the urgent need for raising the attention towards the field of building interventions, rehabilitation included.

Just by comparing the percentage of built newness (buildings younger than 25 years old) with the percentage of built heritage (buildings older than 25 years old); an architect, even if he has never constructed a rehabilitation design development, should at least have simulated few of them, while being oriented and instructed as an architecture student.

The Architect's Council of Europe (CAE, 2005) is very clear about it and states in the *European Deontological Code for Providers of Architectural Services* that they "must respect and help to conserve and develop the system of values and the natural and cultural heritage of the community in which they are creating architecture. They shall strive not only to improve the environment through the highest quality of design but also to improve the quality of the life and the habitat within such a community in a sustainable manner, being fully mindful of the effect of their work on the widest interests of all those who may reasonably be expected to use or enjoy the product of their work".

How can society expect from architects to reach results of sustainable quality and lifespan consciousness while developing rehabilitation designs, if some of them have never been adequately oriented and instructed? It would be the same as placing yourself in the hands of a doctor for a heart surgery, when he did not learn nor practice enough. Would you feel safe? The building also, certainly not!

Back to the fifty-two users, that confirmed their previous experience on rehabilitation designs. They were respectively: fourteen architects (70%) and ten architecture students (50%), from the sample registered from Portugal; and sixteen architects (80%) and twelve (60%) architecture students, from the one registered from Netherlands. The following chapters shall only consider the answers of those users, slightly more Dutch (54%) than Portuguese (46%).

3.3 *The interest of developing rehabilitation designs*

All users (100%), from the four groups, qualified their own rehabilitation designs as interesting. This overall recognition clearly shows an interest from the designers for this category of design developments. The variety of the answers emerges, in the arguments used to justify their considerations, the advantage of the new existence versus the pre-existence and the most important factors that have clearly influenced their designs.

The designs of rehabilitation interventions of built heritage differs from the designs of built newness, mostly due to the fact that there is a pre-existent building or group of buildings; which designers are obliged to consider during their design developments. Along the design process, this pre-existence is converted into a new existence; harmonizing a universe of actions and inherent aims towards the building.

RE-ARCHITECTURE guides the subdivision of this universe in three groups: the actions towards what is being subtracted from the building (subtractions), the actions towards what remains in the building (remainings), and the actions towards what is being added to the building (additions). Accordingly, the degree of harmony between these three groups is directly related to the degree of the designer's lifespan consciousness, as well as, how he considers the building's past, present and future. (Pereira Roders, 2006)

These degrees are not only identifiable in the proposed design solutions, but also in the arguments used by the designers to justify their considerations. Therefore, the arguments used by the fifty-two users, to sustain why their rehabilitation design was considered interesting, were ordered according to their final target; the subtractions, the remainings and/or the additions.

Most answers (71%) could be ordered accordingly. However, there were five users (10%), one Portuguese and four Dutch architects, who placed the interest of the rehabilitation design in other targets rather than the building; however, non less valid. Those were respectively, the degree of sustainability of the intervention; the context as input / guideline (two users), the communication with the involved actors, the integration of past and future. Ten users (19%) did not exactly answer the question, so their arguments were considered invalid.

Table 2 summarizes the users' arguments, ordered according to their final target. It is interesting to verify that only one Dutch architecture student (2%) mentioned the subtractions as argument to sustain her interest for the rehabilitation design.

Table 2. The users' arguments ordered according to their final target

	Architects							Architecture Students						
	S	R	A	R+A	O	I	**T**	S	R	A	R+A	O	I	**T**
Portugal	-	6	1	3	1	3	**14**	-	2	2	4	-	2	**10**
The Netherlands	-	6	-	2	4	4	**16**	1	2	-	8	-	1	**12**

*S = Subtractions; R = Remainings; A = Additions; R + A = Remainings and Additions; O = Other arguments; I = Invalid answer

Far more users considered the remainings (31%) among their arguments. Even more were the ones, arguing both remainings and additions (33%). Surprisingly, the additions were only referenced individually by two Portuguese users (4%), one architect and one architecture student. Interestingly, independent from the country, architects mainly sustained their arguments in the remainings (40%), while the architecture students sustained their arguments in the remainings, combined with the additions (57%).

The users were also asked to describe the advantages the design (new existence) brought to the building + environment (pre-existence). To better synthesize, the universe of answers was ordered according to the five primary aims: decrease, restore, maintain, improve and replace. Again, three answers (6%) did not match such aims and four other (8%) were considered invalid, as they did not respond to the question.

The three that did not match the ordering referenced as main advantage of their design, the contribution to the environment with the building reuse; the art of blending – the remainings with the additions; and the fact that the design was not only made by the user, but also the owners contributed to its quality.

Table 3 summarizes the answers of the forty-five users (83%), ordered according to the five main aims and to the fact if it was a general or a directly consideration pointed to the building or to its environment. As some of the users described more than one advantage, the researcher was able to identify and order a total number of eighty-six advantages. There was a clear tendency to state advantages related to what the user improved (66%) and replaced (22%) with his design; rather than what he managed to maintain (12%), decrease (7%) and restore (1%).

First, the advantages related to what the user "improved" were the most homogenous among the four groups of users. Registered from Portugal; the architects described fifteen advantages (32%), related to the current needs / living standards and the building physics; while the architecture students described only nine (19%), framing both building and environment.

Registered from The Netherlands, the architects described only ten advantages (21%), equally framing the building and environment; while the architecture students described three more advantages (28%), mostly related to the current needs / living standards and the building physics, similarly to the architects, registered from Portugal.

Second, the advantages related to what the user "replaced" were equally considered by the users registered from Portugal (50%) and The Netherlands (50%). Difference is that now, the architects registered from Portugal described very few advantages (5%), compared with the architecture students (45%). This difference is weaker among the users, registered from The Netherlands, where the architects described seven advantages (32%), while the architecture students described only four (18%).

Third, the advantages related to what the user "maintained" were mostly described by the users registered from The Netherlands (70%). Registered from Portugal, only the architects described three advantages (30%), having maintained the tangible heritage within the building, as well as, the environment's history and image concept.

Fourth, the advantage related to what the user "restored" was only mentioned by one architect registered from The Netherlands. Accordingly, the use of "bio-ecological solutions as well as materials" would restore and replace their life cycles, implying the improvement of both building and environment.

Last, the advantages related to what the user "decreased" were exclusively presented by four architects, mostly registered from The Netherlands (83%). There was only one architect, registered from Portugal (17%); together with one architect, registered from The Netherlands who; described as advantage, the reduction of energy losses. The last one even described the reduction of money and resources. The two other users referenced the contribution to the decrease of demolition and to the decrease of little spaces.

Table 3. The advantages presented by the users, ordered by aim

			Portugal			The Netherlands			
			A	S	**T**	A	S	**T**	**T**
Decreases	loss of money		-	-	-	1	-	**1**	**1**
	demolition / loss of resources		-	-	-	2	-	**2**	**2**
	little spaces		-	-	-	1	-	**1**	**1**
	loss of energy		1	-	**1**	1	-	**1**	**2**
Restores	material lifecycles		-	-	-	1	-	**1**	**1**
Maintains	building	old and monumental values	-	-	-	1	-	**1**	**1**
		features and characteristics	-	-	-	1	-	**1**	**1**
		identity	-	-	-	1	-	**1**	**1**
		history	-	-	-	1	1	**2**	**2**
		form	-	-	-	-	1	**1**	**1**
		tangible heritage	1	-	**1**	-	-	-	**1**
	environment	history	1	-	**1**	1	-	**1**	**2**
		image concept	1	-	**1**	-	-	-	**1**
Improves	building	-	-	5	**5**	1	-	**1**	**6**
		coherence between exterior and interior	-	-	-	-	1	**1**	**1**
		current needs / living standards	4	-	**4**	1	2	**3**	**7**
		physics / comfort / light / acoustics / thermal behavior	6	-	**6**	1	3	**4**	**10**
		purpose	-	-	-	-	2	**2**	**2**
		living space / space	2	-	**2**	-	-	-	**2**
		functions / equipments	-	1	**1**	-	-	-	**1**
		aesthetics	-	1	**1**	-	-	-	**1**
		solutions / materials	-	1	**1**	1	-	**1**	**2**
	environment	-	-	2	**2**	3	4	**7**	9
		economic potential and social cohesion	-	-	-	1	-	**1**	1
		contribution for its humanization	1	-	**1**	-	-	-	**1**
		solutions / materials	-	-	-	1	-	**1**	**1**
Replaces	building	uses / functions	1	2	**3**	2	2	**4**	**7**
		image / façades	-	1	**1**	1	-	**1**	**2**
		processes	-	-	-	1	-	**1**	**1**
		identity	-	-	-	1	-	**1**	**1**
		relation with the environment	-	1	**1**	-	-	-	**1**
	lives /activities / dynamics		-	6	**6**	1	2	**3**	**9**
	material lifecycles		-	-	-	1	-	**1**	**1**

* A = Architects; S = Architecture Students; T = Total

The users were also asked to describe the most important factors that have clearly influenced their designs. This time, the answers were not particularly ordered, but grouped when describing the same factor. There were some factors that were specifically related to the building (59%), others to the environment (17%); and others generally related to factors involving both building and environment (24%).

From the universe of eighty-seven important factors there were few (17%) that were only referenced once. The building "accessibility", "surprise", "history", "relation with the environment" and the "involvement with experts and technical knowledge" was only referenced by the architects, registered from Portugal. The building "form"; "changeability"; environment "specifications", "identity", "materials" and "climate"; "time"; "prospects" and "cultural factors" were only referenced by the architects, registered from The Netherlands. Last, the building "condition" was only mentioned by an architecture student, also registered from The Netherlands.

However, the building structure/construction was the most important factor, referenced by fourteen users (27%) from the four groups of users. Referenced by half the number of users (14%), both building qualities/architecture and functions/performances/program were equally referenced; the first one more referenced by the users registered from the Netherlands and the second one more referenced by the ones from Portugal.

Even if few of the important factors described by the users could be part of a broad sustainable strategy, e.g. building, environment, etc.; sustainability was specifically referenced by three users (6%), one architect and one architecture student, registered from Portugal; as well as, one architect, registered from The Netherlands. Even if not considerably representative, it is already better, than no reference at all.

3.4 *The subtractions, remainings and additions*

When directly asked to scale the importance given in their design to the subtractions, remainings, additions, and particularly to the connections between the remainings and the additions; users could choose between a scale of five values; very low, low, reasonable, high and very high. Table 4 describes the scale of importance given by the users to the four realities.

The users registered from Portugal have mostly considered of reasonable importance; the subtractions (29%), the remainings (52%) and the additions (42%). With a slight advantage regarding the users who considered the connections between remainings and additions of reasonable importance (37%), they were mostly considered of very high importance (38%).

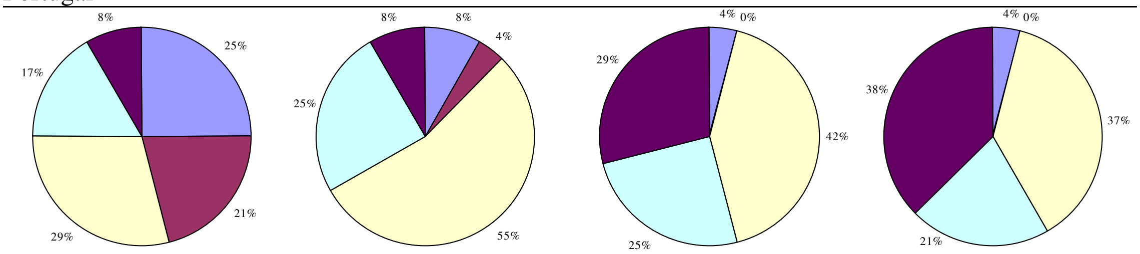
Instead, the users registered from The Netherlands have mostly considered of high importance the remainings (60%), the additions (39%) and the connections between remainings and additions (57%). Again, with a slight advantage regarding the users who considered the subtractions of high importance (36%), they were mostly considered of very high importance (39%).

When just focusing on what the users considered of very high importance; we can easily verify that the subtractions and remainings were less valued than the additions and connections (between remainings and additions), in both countries. Probably that is because, often designers do tend to overvalue what they add, rather than what they subtract and remain from the preexistence; which is the first motive why they are involved in such a rehabilitation intervention.

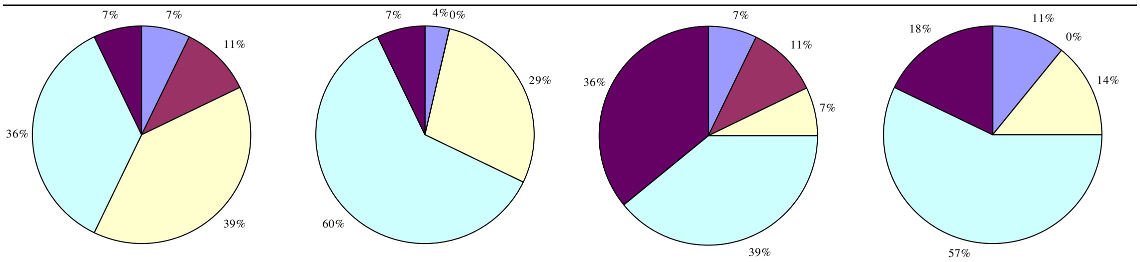
That is even shown more clearly in the following results: when asking if they did plan what to do with the subtracted, remaining, and added elements, as well as, with the connection between the remaining and added elements; users were also asked to select the classification that would better describe their main aim. Moreover, they should provide a justification, as well as, an example from their design that could illustrate this aim.

Table 4. The scale of importance given by the users in their design

Portugal



The Netherlands



Subtractions Remainings Additions Connections

* very low ■ low ■ reasonable ■ high ■ very high

The subtractions were part of the design plan considerations by twenty-five users (48%); comprising ten architects (71%) and four architecture students (40%), registered from Portugal; in addition to eight architects (50%) and three architecture students (25%), registered from The Netherlands. When asked about their main aim, most users selected "reuse" (64%), five selected "relocate" (20%) and four selected "recycle" (16%). "Reuse" was the main aim of most architecture students, registered from both countries and of the architects, registered from Portugal. Instead, "recycle" was the main aim of most architects, registered from The Netherlands.

More than the subtractions, the remainings were planned by thirty-seven users (71%). Except for the six architecture students (60%), registered from Portugal, more than seventy percent of the users, from the other three groups, planned what to do with the remained elements. All groups have selected "repair" as the classification that would better describe their main aim. However, while the users registered from Portugal equally selected the highest scale of classification, "consolidate"; the users registered from The Netherlands equally selected a lower scale of classification, "reinforce".

As foreseen, the additions were the most planned from the four realities, by forty-nine users (94%). Only one architect (7%) of the fourteen registered from Portugal; and two architecture students (17%), registered from The Netherlands; answered not to have particularly planned what to do with the additions. Probably, that had to do with their lower scale of intervention, where only minor additions were made. In the four groups of users, most additions (60%) were located "inside, connected" with the remainings. Nonetheless, there were already few users that planned their additions "outside, apart" from the remainings (20%); or "inside, demountable" (16%).

Less than the additions, the connections between the additions and remainings were planned by forty-three users (83%) comprising thirteen architects (93%) and eight architecture students (80%), registered from Portugal; in addition to fourteen architects (88%) and eight architecture students (67%), registered from The Netherlands. The architects registered from both countries have mostly selected the classification "punctually fixed" (23%), to classify their main aims. In contrast, most architecture students (15%) selected "totally fixed". Generally, most groups selected the classification "demountable" and "loose", except for the architecture students; respectively registered from The Netherlands and Portugal.

The second part of the sub-questions – its justification and example – had the particular purpose to verify the consistency of the first part of the sub-questions. Generally, when someone; would have planned particularly each of the four realities; would not have any problem finding the sustaining argument and/or an example within his design developments that could exactly illustrate how he managed to achieve such main aims.

Curiously, when considering valid only the answers that provided an example, a major number of users that initially affirmed to have had a particular plan for those four realities fall immediately into the group of users that had no particular plan for them. This reduction is quite considerable; of approximately fifteen users (30%) for the subtractions, remainings and additions; and of exactly thirty users (60%) for the connections between the remainings and connections. Nevertheless, the global overview of their main aims towards the four realities did not change so much.

There are, however, some interesting justifications for such main aims, among the answers given by all users, inclusive the ones that did not provide any example. With no reference to "reprocess" among the main aims towards the subtractions; there are, though, references to the "reuse of the existing structure to sustain the new elements", the "relocation of stone elements" and the "recycle of concrete and steel".

Again, with no reference to "arrest decay" as main aim towards the remainings, several were examples of main aims to "repair windows"; to "reinforce the construction / structure" and to "consolidate the finishings". For the additions, all main aims were illustrated with examples to add; "outside the building elements that would bring too much destruction to the building"; and to the inside the building; "fixed new floors", "demountable partition walls" and "loose volumes". Last, the examples illustrating the connections between the remainings and additions gave only more detail to the previous answers, without generalizing how they were aimed, for this particular design.

3.5 *The subtractions versus remainings versus additions*

Considering the pre-existence, users were asked about the percentual relation, between subtractions and remainings. Figure 1 illustrates their answers, filtered per group. Most users selected the relation fifty | fifty (33%); however, the second place is the relation seventy-five | twenty five (25%), followed by the relation ninety-five | five (19%). Only afterwards comes the relation twenty-five | seventy-five (15%); and as last, the relation five | ninety-five (8%).

Similar results were presented in figure 2, illustrating the answers of the users, also filtered per group, when asked to consider the new existence, and the percentual relation, between additions and remainings. There are however, some differing points. No architecture students registered from Portugal selected both relations five | ninety-five and seventy-five | twenty five; and no architect, registered from The Netherlands, selected the relation ninety-five | five.

Figure 1. The Subtractions versus Remainings

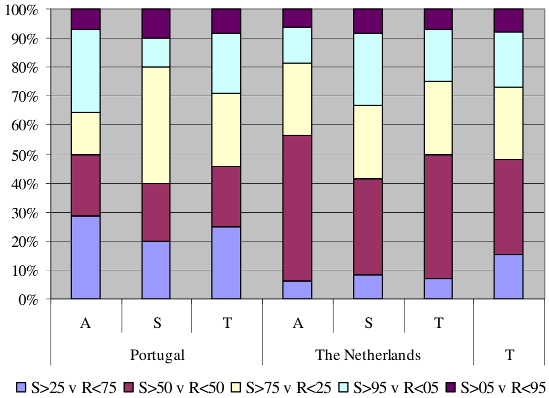
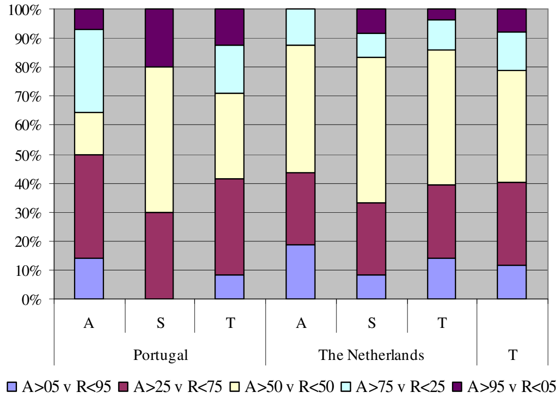


Figure 2. The Additions versus Remainings



4 CONCLUSION

One could argue that just by rehabilitating buildings from the built environment, designers are being already sustainable. That can be true, even in very high scales of rehabilitation, in the sense that the urban infrastructures and services are reused and it is not necessary to go to the natural environment and make it suitable to the current living, working and leisure needs.

On the other hand, rehabilitation interventions can cover serious degrees of lifespan unconsciousness, behind very modern and fashionable additions; neglecting its past, present or future. After the rehabilitation intervention is finished, too often, is impossible to discern what was subtracted, what remained and what has been added. Even more difficult is to understand the logic behind some design decisions, when simply comparing its advantages and consequences.

One needs to assess the effective relation and degree of harmony between these three realities, in order to determine how sustainable a rehabilitation intervention or its designer really is. There are no receipts to follow in every building, as various aims might seem totally sustained for one building, and result totally unsustained for others. It truly depends on the significance and condition of a building and respective environment identified during a pre-design stage.

Therefore, as a preliminary conclusion of the survey results, it can be stated that sustainability is a factor that is emerging into the world of the designers, from Portugal and the Netherlands, involved in rehabilitation developments. Nevertheless, this path is still long and requires the serious effort to recognize that not all design solutions that might initially seem very original are actually suitable. They might bring irreversible consequences, not only to the building, but to the natural and built environment. Future generations shall surely valorize the effort.

REFERENCES

Alves de Medeiros, A.K. 2006. *Genetic Process Mining*. Eindhoven: TU/e.

CAE. 2005. *European Deontological Code for Providers of Architectural Services*. Brussels: CAE.

Pereira Roders, A. 2006. *RE-ARCHITECTURE scapus: Lifespan rehabilitation of Built Heritage*. Eindhoven: TU/e.

Sustainable management of building stock refurbishment by using MCDM

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ABSTRACT: A large proportion of residential building stock in most developed countries is old and in need of refurbishment. Funding for such activities is always limited, therefore rational methods have to be employed to determine the extent of refurbishment and associated actions. The paper presents a computer supported multi-criteria decision model (MCDM) for the selection of a portfolio of refurbishment actions with highest cumulative utility score. A financial constraint can be imposed upon the solution. Mathematically, the model is based on the knapsack problem. Results for a case study of a multi-apartment building, where two criteria are used (functionality and sustainability) show that the total utility score depends strongly upon the selected relative importance of criteria employed.

1 INTRODUCTION

The majority of European countries have experienced an increased rate of residential construction in the period after the World War II. Due to enlarged needs of the population, large neighbourhoods consisting of multi-apartment buildings were built in that time. Condition monitoring of this residential stock shows that today, these buildings often fail to comply to contemporary living standards in terms of the size and human comfort as well as to building regulations related ot thermal and acoustic insulation and structural safety. As a consequence, increased migration of the tenants was observed in large neighbourhoods from this time period over the past two decades (Žarnić & Šelih, 2004).

In general, two options are available for the management of these buildings: demolition and construction of new buildings complying to contemporary requirements, or refurbishment of existing buildings. Following the sustainability principles applied to the built environment (Agenda 21, 1999), and considering the proportion of the building stock from the discussed period, in most cases, refurbishment is preferred to demolition. Asset management of this building stock integrated with maintenance management is therefore indispensable if adequate performance of the stock over its entire life cyle is to be achieved (Vanier, 2001).

Asset management of multidwelling residential stock is a complex process consisting of several steps. First, asset inventory has to be created. The performance requirements have to be identified and the condition of the each building forming the building stock has to be assessed by using a pre-defined assessment methodology. For all buildings under consideration, a decision between maintenance and refurbishment has to be made. If the condition of the building requires refurbishment, the process of refurbishment planning can be initiated.

A detailed comprehensive assessment of the existing state of the building and identification of elements with insufficient performance that consequently require repair, upgrading or replacement has to be carried out for buildings where the decision to start refurbishment has already been taken. The market offering products, materials and components to be used in refurbishment is marked by extensive development. As a consequence, a number of various alternative refurbishment actions can be used for each element with unsufficient performance.

In addition, the realization of some objectives seems more rational from the cost perspective than from other perspectives, which makes the decision process on selecting the "best" set of refurbishment actions complicated (Zavadskas *et al*, 2004).

These decisions are mainly made by a design team that consists of a design group, a client and, depending on the type of the building contract, a representative of the contractor. The design group typically includes an architect, a structural engineer, a HVAC engineer and an electricity engineer. A consensus between the members of the design team in as many as possible points of view has to be achieved if an optimum solution is to be found. Within this process, it is extremely important to capture the requirements of the client / user of the building. New building design as well as design of refurbishment of existing buildings is therefore an iterative process (Alanne, 2004).

Identifying the best combination poses a real challenge for the decision maker – the design team. Both functional and visual aspects have to be accounted for. In addition, as the awareness of the importance of sustainable development is increasing, the environmental performance of the refurbished building is becoming an essential criterion used in the selection of a set of refurbishment actions to be employed as well.

Refurbishment design can be viewed as selection of a set of various refurbishment actions, selected from a wide range of viable actions. The selected portfolio should have the largest value possible, where the value is judged by several pre-defined criteria. As already discussed, the number of possible actions is large, therefore the use of a computer-based decision support tool is indispensible if the optimum selection of actions is to be achieved.

Existing decision support tools are aimed at supporting the condition-rating process and at assessing the total value of the selected set of actions (Zavadskas *et al*, 2004, Rosenfeld & Shohet, 1999; Balaras, 2002; Flourentzos *et al*, 2004) with respect to the selected criteria. However, these tools do not take into the account the inevitable real life monetary limitations that accompany each refurbishment and simultaneously ensure the maximum value of the planned refurbishment.

The goal of this paper is therefore to present a mathematical model to be used for selection of the most valuable set of refurbishment actions from a comprehensive range of available actions. The value, or the total utility score, depends upon the selected criteria and their relative importance. The tool is based on multi-criteria decision method and takes into the account the financial constraint that limits the choice of actions. By using the model, the design team can select a set of options, i.e. refurbishment actions that yield a maximum total value for the decision maker while the total cost does not exceed the financial constraint. Functional and environmental aspects of each feasible refurbishment action are considered. Mathematically, the model is based on the knapsack problem solution that leads to an optimized portfolio of actions.

2 METHODOLOGY

Conventionally, once it is decided that the refurbishment will be carried out, the designers generate a few design alternatives, which are then evaluated by the design team. A limited number of alternatives can be assessed if evaluation is based solely upon the experience of the members. Therefore, an automated decision support model has to be used if a larger number of alternatives is to be evaluated.

In this paper, refurbishment of a building is considered as a set of single actions that are expected to increase the sustainability and functionality of the building. Each action is therefore assessed by these two criteria. The single actions are members of a comprehensive list of all feasible actions.

The possible refurbishment actions, or decision variables, are labelled as

$$a_1, a_2, \ldots, a_i, \ldots, a_n$$

where $a_i \in \{0,1\}$. $a_i = 1$ if the action is carried out, else $a_i = 0$. n is the total number of all viable actions.

Total utility score, S_{tot}, is defined by the expression

$$S_{tot}=\sum_{i=1}^{n}(a_i S_i) \quad (1)$$

where S_i is the utility score achieved by selecting the renovation action a_i. Refurbishment should result in maximum total utility score, therefore the function

$$\sum_{i=1}^{n}(a_i S_i) \quad (2)$$

is the objective function of the problem to be solved. The problem solution is subject to constraint

$$\sum_{i=1}^{n}(a_i C_i) \le C_{\max} \quad (3)$$

where C_i is the cost of the individual action a_i, and C_{max} is the maximum total allowable cost of the refurbishment project.

In addition, the problem may be subject to other constraints that define

- which actions can or have to be carried out at the same time;
- necessary actions for the building (case-based constraints);
- minimum required performance (user-defined constraints); and
- other constraints, such as constraints dictated by laws or regulations.

The mathematical form of above listed constraints depends on the case under consideration and has to be studied individually for each case. Thorough knowledge of possible refurbishment actions and their interaction is required to determine the actions' compatibility.

The importance of different criteria used in the selection of actions can be captured by assigning criteria weights, w_j, to indicate their relative importance, where the sum of all criteria weights equals to 1 as presented in Eq.(4). m is the number of criteria employed in the decision process.

$$\sum_{j=1}^{m} w_j = 1 \quad (4)$$

Assigning the importance to individual criteria has to be performed prior to selection process and is the responsibility of the decision-making team.

Utility score for action i, S_i, can be seen as a value that can be expected by a decision maker when selecting an option. Each action is assigned a utility value S_{ij} related to the individual criterion j used in the analysis.

$$S_i = \sum_{j=1}^{m} w_j S_{ij} \quad (5)$$

Total utility score of a set of actions is the sum of utility values of all actions selected. The objective of the decision process is to select a set, or a portfolio, of actions that results in maximum total utility score (Eq.2) according to the criteria and their relative importance by taking into the account the financial constraint (Eq.3) and compatibility constraints defined for each individual case. The problem can be solved numerically by using the SOLVER function provided by the MS Excel software.

The cost of the selected portfolio, C_{tot}, of refurbishment actions is the sum of costs related to chosen actions.

$$C_{tot} = \sum_{i=1}^{n} a_i C_i \quad (6)$$

3 CASE STUDY

3.1 *General data*

Refurbishment of a residential multi-apartment building was selected to demonstrate the use of the presented multi-criteria decision support system for selection of refurbishment actions. The building under consideration was built in 1960. Total heated area of the building is 1860 m^2, and the total envelope area (in contact with environment) is 1191 m^2. The windows' area is 189 m^2. Existing envelope consists of prefabricated concrete plates with the thermal insulation core 8 cm thick, and the plate has a total thickness of 16 cm. The building dates from the period where no energy efficiency codes existed. An assessment showing that 40% of the energy could be saved by improving the thermal envelope was carried out in 2003. The recommendations made at the same time conform to the new thermal efficiency code from 2002. The energy loss could be reduced by adding insulation to the exterior walls or to the roof. The appearance of the building was visibly degraded, and there was a clear need for a new façade.

The actual list employed in the study was longer, however for the sake of clarity of the paper, a reduced list of 22 refurbishment actions was extracted. The listed actions can be divided into the 6 groups according to their effects as described in Table 1. The cost of each action and assigned utility values $S_{i,j}$ for the criteria employed in the analysis are presented in Table 2.

Table 1. Groups of actions considered in the case study analysis.

Group	Description	No.of options	Actions No.
I	Additional insulation of exterior walls	3	1,2,3
II	Façade change	3	4,5,6
III	Roof change	2	7,8
IV	Window change	6	9,10,11,12,13,14
V	Additon of shading devices	5	15,16,17,18,19
VI	Balcony alternation	3	20,21,22

A refurbishment action can affect the functionality either in positive or negative way, therefore the scale for the utility values used in Table 2 ranges from -10 to 10 for the functional criterion. In the case study presented, the environmental aspect is considered to be related to energy efficiency only, and no other environmental effects related to the production of materials required for the execution of a particular action are accounted for. The scale for the utility value for the environmental criterion ranges therefore from 0 to 10 as the adverse effect of the action upon the environment is not possible.

Only one action can be chosen out of each group listed above. For the first group of actions, this constraint can be mathematically expressed as

$$\sum_{i=1}^{3} a_i \leq 1 \qquad (7)$$

Equivalent expressions can be written for all 6 groups of actions presented in Table 1.

Theoretically, if no constraints were imposed to the selection problem and there would be no dependences among the activities, there would be 2^{22} alternative sets of selected actions for the case presented. The use of decision tool presented leads to selection of the activity set with maximum total utility score with respect to the chosen combination of criteria.

3.2 *Utility values for individual actions*

Several goals should be attained by the selected set of refurbishment actions. Thermal efficiency of the building should be improved in order to reduce the energy required for the heating and the associated CO_2 release. Therefore, the largest environmental utility values are assigned to actions where thermal insulation is added to the building envelope and change of windows. Values presented in Table 2 are a first judgment that can be quantified more precisely by a detailed energy losses calculation for each action.

Table 2. List of possible refurbishment actions, their costs and selected values for environmental and functional utility values.

		Cost (EUR)	Utility values	
i	Description of refurbishment action	C_i	$S_{i,env}$ [0,10]	$S_{i,funct}$ [-10,10]
1	Thermal insulation on outside wall (d=4 cm)	7.5/m²	2,00	-1,00
2	Thermal insulation on outside wall (d=6 cm)	8.3/m²	5,00	-3,00
3	Thermal insulation on outside wall (d=8 cm)	9.6/m²	7,00	-5,00
4	Façade – type A composite system	17.5/m²	0,00	-1,00
5	Façade – type B	121.7/m²	0,00	-2,50
6	Façade – type C	32/m²	0,00	-4,00
7	Flat roof type A (RC concrete, mineral wool (6 cm), waterproof layer, gravel)	138/m²	1,50	3,00
8	Flat roof type B (RC concrete, mineral wool (6 cm), waterproof layer, concrete plates)	150/m²	1,50	5,00
9	Wooden window (140 x140), standard double glass	167/piece	0,80	1,00
10	PVC window- discontinuous thermal bridge, double sealing (140 x 140 cm), standard double glass (U=1.5 W/m²K)	208/piece	0,50	2,00
11	Al. window – discont. thermal bridge, double sealing (140 x140 cm), standard double glass (U=1.5 W/m²K)	250/piece	0,50	2,00
12	Wooden window (140 x140 cm), standard double glass with pattern	183/piece	0,80	1,00
13	PVC window- discontinuous thermal bridge, double sealing (140 x140), standard double glass with pattern (U=1.5 W/m²K)	230/piece	0,50	2,00
14	Al. window – discontinuous thermal bridge, double sealing (140 x140 cm), standard double glass with pattern (U=1.5 W/m²K)	275/piece	0,50	2,00
15	Exterior shading device - wood shutters	146/piece	0,20	0,50
16	Exterior shading device – PVC shutters	187/piece	0,20	1,00
17	Exterior shading device - Al shutters	229/piece	0,20	1,00
18	Interior shading device - Venetian blinds	20.8/m²	0,00	3,00
19	Exterior shading device - roller shutters	146/window	0,10	2,00
20	Standard iron balcony fence	125/r.m.	0,00	1,00
21	Forged iron balcony fence	250/r.m.	0,00	1,00
22	Brick wall fence of 90 cm height, marble shelf	83/r.m.	0,00	2,00

Functionality is a subjective issue, to a large extent depending on the preference and experience of the evaluator. In this paper, utility values for functionality are determined with respect to ease of execution, reliability, serviceability and its impact upon physical characteristics of the refurbished building as proposed in (Alanne, 2004).

It should be noted that assigned values for utilities of separate actions, S_{ij}, are based on personal judgement and can be viewed as a first approximation. In order to ensure objective selection process, utility values that are either obtained quantitatively, or as a combination of opinions of several experts from relevant fields, should be used.

4 RESULTS AND DISCUSSION

Various weighting combinations of the criteria employed were taken into the account in the analysis. First, selection of refurbishment actions was carried out by taking into the account each single criterion (Table 3, options 100/0 and 0/100). Secondly, varying relative importance was assigned to both criteria taken into the account (Table 3, options 25/75,50/50, 75/25).

Table 3. Combinations of criteria weights employed in the analysis; number of criteria, m=2.

Label	Criterion	
	Environmental (j=1)	Functional (j=2)
	w_1	w_2
0/100	0	1,00
25/75	0,25	0,75
50/50	0,50	0,50
75/25	0,75	0,25
100/0	1,00	0

Table 4**.** Overview of actions selected by using different weighting combinations at financial constraint of C_{max}=100000 EUR (1=selected action).

Action, *i*	Criteria weighting combination				
	0/100	25/75	50/50	75/25	100/0
1	0	0	**1**	0	0
2	0	0	0	0	0
3	0	0	0	**1**	**1**
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	**1**
8	**1**	**1**	**1**	**1**	0
9	0	0	**1**	0	**1**
10	**1**	0	0	**1**	0
11	0	**1**	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	**1**
16	0	0	0	0	0
17	0	0	0	0	0
18	**1**	**1**	**1**	**1**	0
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	**1**	**1**	**1**	0	0
Total cost, C_{tot} (EUR)	93.820	97.153	99.419	86.992	87.719
S_{tot}	12,00	9,63	7,40	8,38	10,00

Financial constraint employed in the analysis was taken as 100.000 EUR, which, when divided by the number of apartments, results in a viable financial contribution of the each resident.

The results for the decision variables a_i (1 if action is selected, 0 is not selected) obtained by the SOLVER procedure are summarized in Table 4 for all weighing combinations defined in Table 3. It can be seen that total utility score, S_{tot}, is significantly influenced by the combination of criteria weights employed.

If only environmental criterion is taken into the account, the thickest thermal insulation on the wall (action 3) is chosen. Flat roof type A is selected. No façade change will be carried out. Wooden windows with standard glass and wooden shutters (actions 9 and 15) are added to the selected set of refurbishment actions. Actual costs associated with the execution of selected portfolio of actions are smaller than the allowable sum of 100.000 EUR for all weighting combinations; if only environmental effects are taken as relevant (weighting combination 100/0), the difference between allowed and actual total cost amounts up to 22%.

Analysis of separate contributions to total utility score and cumulative cost is presented in Table 5 for 2 criteria weighting combinations, 50/50 and 100/0. It can be noticed that the utility scores for separate actions as well as the total utility score depend strongly upon the weighting combination employed. If the solution is judged according to the environmental criterion only, the maximum possible total utility score equals to 10,0. If both criteria are considered equally important, the maximum possible total utility score is 7,40, at cost of 99.419 EUR.

Table 5. Costs (C_i) and contributions to utility score (S_i) of selected actions for criteria weighting combination 50/50 and 100/0 (environmental criterion only); financial constraint equals to 100000 EUR (only selected actions are presented).

Crit.weighting comb.: 50/50			Crit.weighting comb.: 100/0		
Action, i	C_i (EUR)	S_i	Action, i	C_i (EUR)	S_i
1	8.933	0,50	3	11.414	7,00
8	55.645	3,50	7	51.305	2,00
9	13.333	0,90	9	13.333	0,80
18	3.267	1,50	15	11.667	0,20
22	18.242	1,00	**Σ**	**C_{tot} =87.719**	**S_{tot} =10,00**
Σ	**C_{tot} =99.419**	**S_{tot} =7,40**			

Figure 1 presents the changes of cumulative utility score as the allowed total cost of refurbishment increases for criteria weighting combinations 100/0, 50/50 and 0/100. Again, the attained total utility score depends to a large extent upon the selected relative importance of criteria. The score increases with increasing financial constraint. It should be noted that the actual cost of the planned refurbishment obtained by the decision model is smaller than the constraint imposed upon the solution. The figure shows that the obtained solutions at financial constraint of 100.000 EUR are close to the “best“ solution possible where no financial constraint is applied.

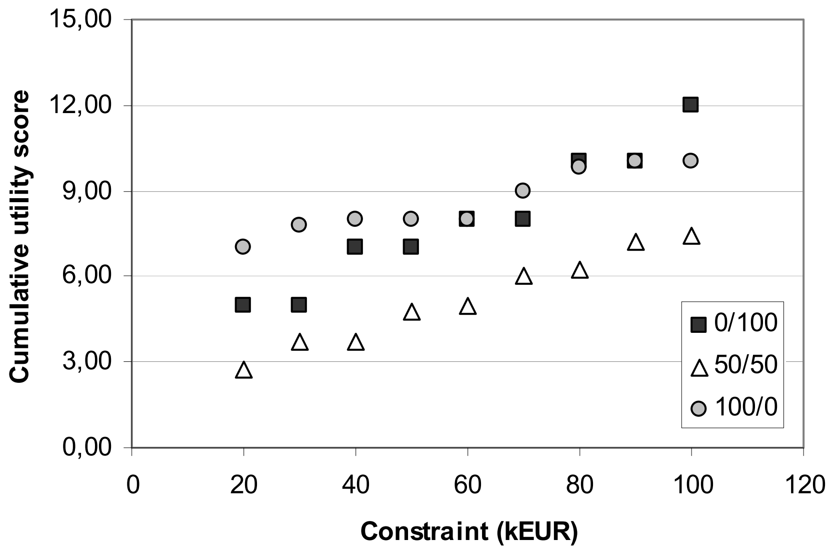

Figure 1. Dependence of cumulative utility score upon allowed total cost of refurbishment (financial constraint in the knapsack problem) for criteria combination 0/100, 50/50 and 100/0.

5 CONCLUDING REMARKS

The importance of maintenance and refurbishment of the built environment is increasing in all developed countries, therefore rational approach has to used in order to maximize the outcome of refurbishment actions.

The number of construction products and methods available at the market to be used in refurbishment is continuously increasing, and the refurbishment planner is facing a large number of possible combinations. At the same time, every case is associated with several compatibility constraints as well as financial constraint imposed by the available funds. The paper is proposing a simple and effective approach in selecting the refurbishment actions from a wide range of possible solutions. The automated decision support tool allows the user to assign variable level of importance to each criterion employed. It is important that the selection of criteria weights employed in the analysis is carried out by the decision maker prior to the analysis.

The main challenge for the practitioner who wants to employ the proposed model is first to identify all possible refurbishment options. This can only be done if analysis of the current state is carried out thoroughly, so that the full list of existing problems can be compiled. Problems that pose a threat to safety and health of the residents, such as insufficient structural integrity, have to be clearly indicated as actions for their mitigation have to be taken regardless of the associated cost. Next, the compatibility of remaining actions has to be analyzed carefully in terms of materials, ease of execution, visual appearance and other aspects. This analysis results in additional set of constraints that has to be used in the decision process. The assignment of the utility values for separate refurbishment actions needs to be established on rational basis. Finally, once the solution is obtained, it should be evaluated in terms of the potential incompatibility of the selected actions in an integral fashion.

REFERENCES

Agenda 21 on sustainable construction. 1999. CIB Report – Publication No.237. Rotterdam, The Netherlands, Conseil International de Bâtiments.

Alanne, K. 2004. Selection of renovation actions using multi-criteria “knapsack” model. *Automation in Construction*, 13: 377-391.

Balaras, C.A., 2002. TOBUS – A European method and software for office building refurbishment. *Energy and Buildings*, 34: 111-112.

Flourentzos, F., Droutsa, K., & Wittchen, K.B. 2000. EPIQR software. *Energy and Buildings*, 31: 129-136.

Kaklauskas A., Zavadskas, E.K.& Raslanas, S. 2005. Multivariant design and multiple criteria analysis of building refurbishments. *Energy and buildings*, 37: 361-372.

Rosenfeld, Y., & Shohet, I.M. 1999. Decision support model for semi-automated selection of renovation alternatives. *Automation in Construction*, 18: 503-510.

Vanier, D.J. 2001. Why industry needs asset management tools. *J. of Computing in Civil Engineering*, 15: 35-43.

Zavadskas, E.K., & Vilutiene, T. 2006. A multiple criteria evaluation of multi-family apartment block’s maintenance contractors: I – Model for maintenance contractor evaluation and the determination of its selecting criteria. *Building and Environment*, 41: 621-632.

Zavadskas, E.K., Kaklauskas, A., & Gulbinas, A. 2004. Multiple criteria decision support web-based system for building refurbishment. *J. of Civil Engineering and Management*, X: 77- 85.

Žarnić, R., & Šelih, J. 2004. Envelopes of multi-storey residential buildings erected from 1946 to 1980. In: Radić, J. (Ed.). Durability and Maintenance of Concrete Structures: Int. Symposium, 21-23 Oct., Dubrovnik. Croatian Soc. of Struct. Engineers (CSSE) and Austrian Soc. for Concrete and Construction Technology (ASCCT), 99-106.

Renewal of a big high density housing block in Berlin Kreuzberg.

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ABSTRACT: This project is the renewal of a large high density-housing block built in West Berlin (Kreuzberg) in the ’60, called “Grey Louse”. The plan had to deal in one hand with complex social issues and in the other with technical and economic constraints that this kind of profit mass housing gives. Kreuzberg is a multiethnic district and the most users living in this building are subsidy aided. The first step was to avoid the usual way of demolition/reconstruction (and so the gentryfication process), following a strategy to improve the high site potential the and keeping the actual users. The strategy applied in this project was: the fragmentation of the block in 4 parts, the involvment of users in the design and the low economic profile of tecnology in the proposed solutions.

1 THE HOUSING HERITAGE FROM THE ’60 IN EUROPE.

The condition of the greater part of the housing heritage built between the ’60 and ’80, seems to be in the urgent needs of refurbishment an renewal, concerning social, energetic, technological and infrastructural issues.

The past vision of large social clusters with few collective scenarios crumbled with the end of the emergency of housing need after the war, the common rise of the life quality, and, above all, with the emerging of unexpected social situations, like immigration, that nowadays involves the whole Europe.

These conditions have produced since the ’80 a rise of the general renovation demand of the housing building stock.

2 THE “GRAY LOUSE” OF WASSERTORSTRASSE IN BERLIN.

The project is a renewal of a big high density-housing block built in West Berlin (Kreuzberg) in the ’60, ironically called “Grey Louse” by the district’s inhabitants. The planned intervention had to deal in one hand with the complex social issues and in the other with structural and economic constraints that this kind of mass housing’s architecture gives.

Kreuzberg is a multiethnic district and in the building lives users that are in the greater part subsidy aided. The first step was to avoid the usual demolition/reconstruction attitude within the gentryfication process, elaborating strategies able to improve the high potential of the site and to keep the actual users in order to preserve the “human landscape”.

This building was constructed at the end of the ’60, by the GEWOBAG Company, as the most in the district, with a prefabricated concrete panels building system (15 cm of thickness), very dense (from 2.4 to 3.5 m of span). The building is 15 floors high, hosts 280 flats whose surface is mainly of 56 and 74 sqm and a few of 32 sqm, arranged in only one single standard floor.

The general degraded state of this building is due to the low quality of construction materials that gives also negatives performance in energy consumption and life quality, and to a social complexity condition, like overpopulation of inadequate size flats.

figure 1. Overview of the project site and the building in Wassertorstrasse in Berlin Kreuzberg.

3 STRATEGY OF FRAGMENTATION.

The whole solid building was divided into 4 “unit” houses (as load bering structure suggest) allowing in this way to consider progressive renewal intervention from unit to unit. A structural/functional building scheme has focused different layers of intervention corresponding to different floor position (ground, standard floor, upper floors)

Fragmentation strategy correspond to the needs of a long term building cost management in order to guarantee the renewal reliability in this particular kind of social and economic context. fragmentation strategy means also to observe and to test the results of the intervention in any unit, having the opportunity to change and optimize solutions, always involving the users in the process. The fragmentation into 4 houses aims to better coagulate neighbourhood relationships, to ensure a good security level and to break the typical impersonality feeling of this kind of high-density building of the ’60. The improving the sound insulation will provide a better privacy too.

As told before, the actual range of flats is of 3 types (34-57-74 sqm) arranged in one only standard floor. The fragmentation strategy allows a partial redistribution of the apartments in order to offer an adequate range of types to different users with different needs, setting a typological matrix of 26 types arranged on 4 floors, considering the partecipation of the users in the design process.

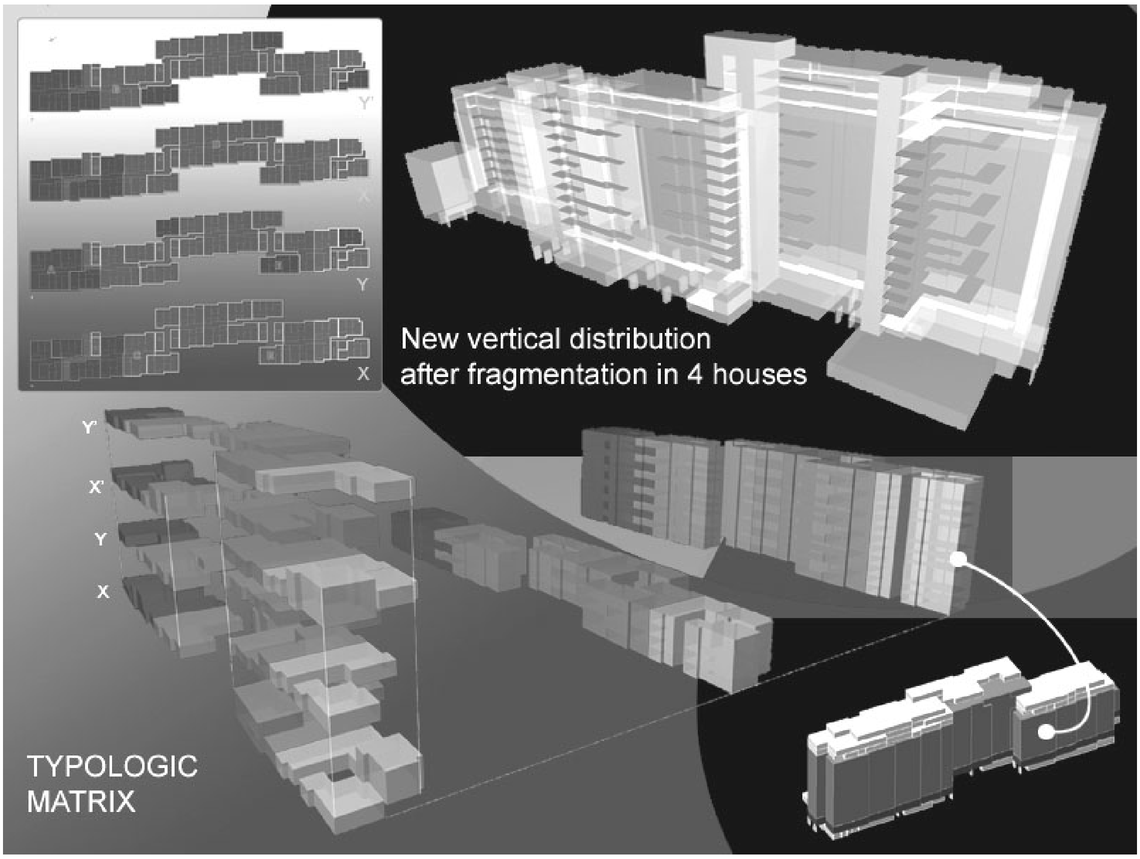

Figure 2. Fragmentation in 4 houses with new distribution and scheme of typological matrix on 4 floors.

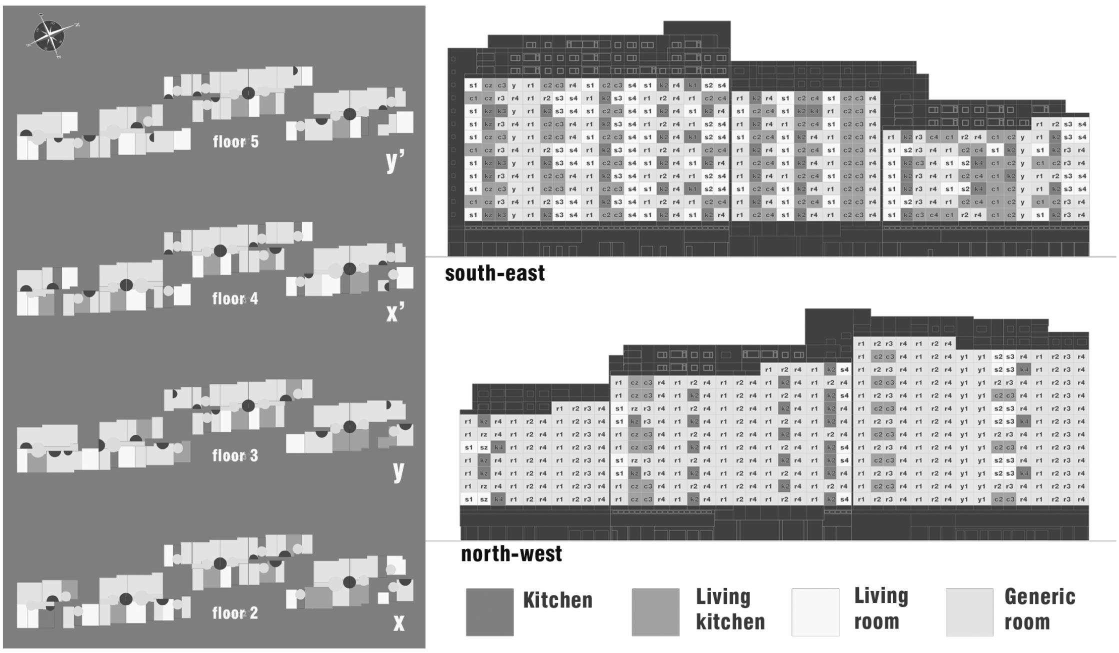

Figure 3. Virtual plan concerning the use of room for the composition of the external enclosure system.

A façade scheme was compiled setting a virtual "use plan" of every room. On this base was elaborated a courtain wall, 1 meter deep, on a semi-indipendent external structure. This "skin" is composed by 4 basic enclosure systems and their variation, depending by environmental factors.

These systems were conceived to be an external interface that use only save/gain energy technology, combining many factors that comes from the environment and from the interior of the building. The opportunity to set the façade in relation with climatic and seasonal condition make this building (basically every single room) react continuosly where is worth to do it, and changing as a green façade do. Terrace, wide windows and the way to *stare* at them are conceived to enjoy the potential of the landscape.

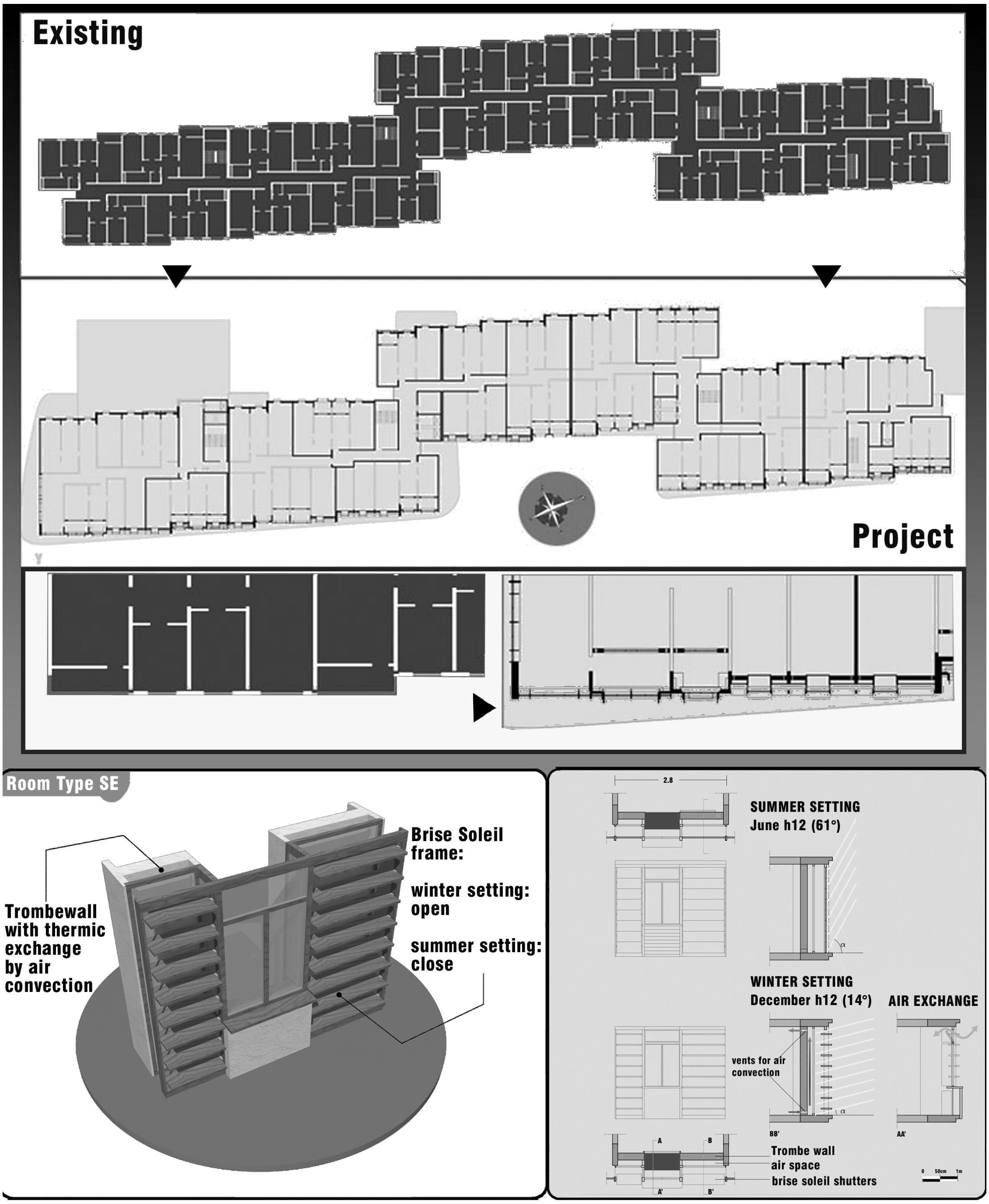

Figure 4. transformation of distribution and detail on the substitution of the facade .Example of one type of modular closing system with bioclimatic solutions.

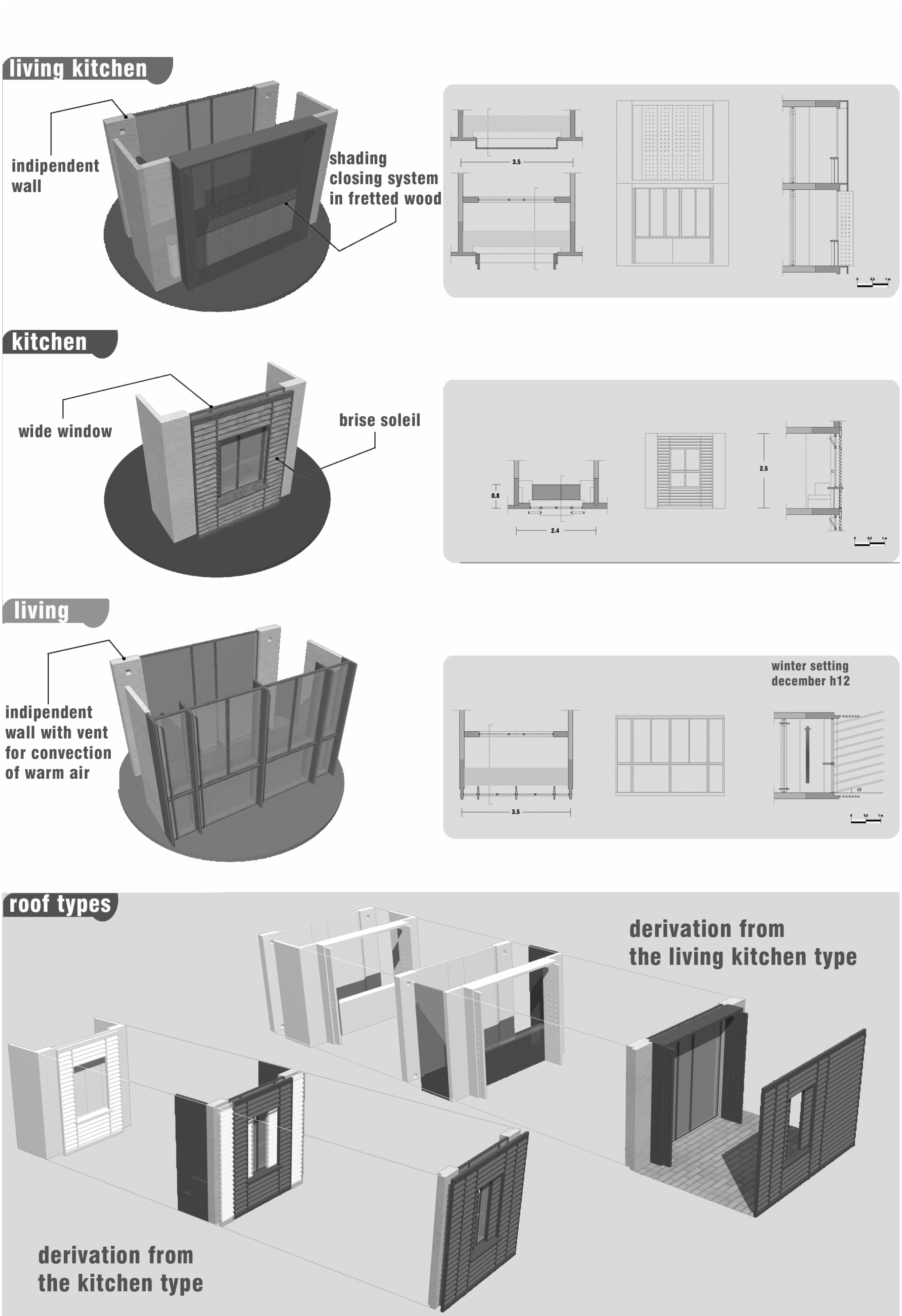

Figure 5. Other modular closing system of the facade and their derivation for the higher floors.

The external enclosure systems on higher floors are adaptions of some modular panel of the middle part to the relevant air turbolences. This need match with the intention to give a “roof” to the building and then to obtain a more reassuring visual impact with the context.

In this way the enlargement of the street tunnel aims to turn off the barrier building in a “district portal” concerning the urban dynamics of the site.

On the roof thermosolar panels are planned for water warming. On groundfloor passages are restored and unused rooms are redistribute to improve the Gallery (in the former commun laundry) as social cathalist.

A “light building site” was planned in order to keep tenants in their flats and to make affordable the intervention discomforts, providing containers as forniture storage or room substitution. The building site is large as two flats and it can shift gradually by moving hits elements orizontally.

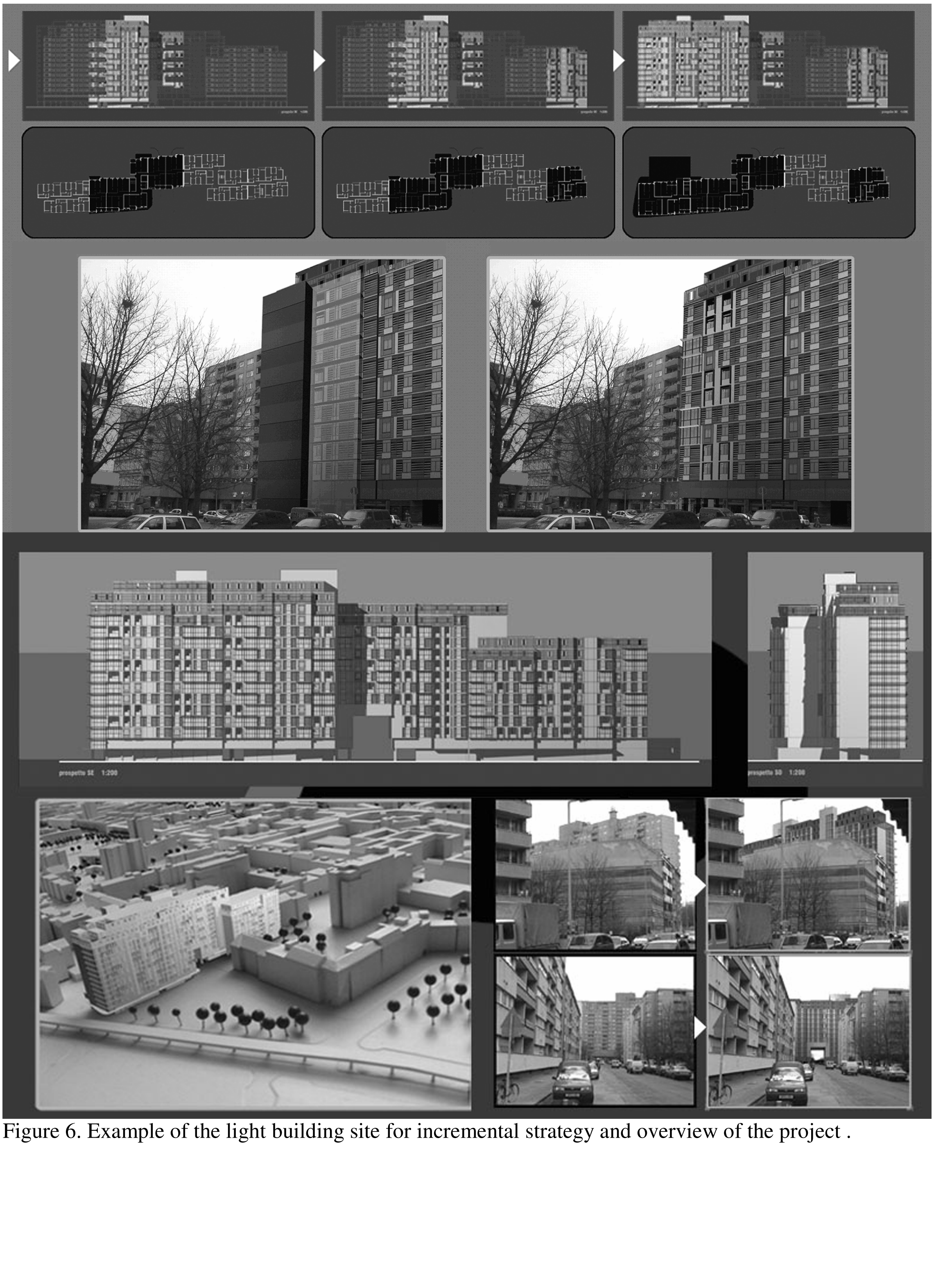

Figure 6. Example of the light building site for incremental strategy and overview of the project .

4 CONCLUSIONS.

First consideration must be about the context of the mangement of the existing building stock of the ’60 speculation. It still remain an emergency situation related to this problem, expecially considering the renovated trend of total demolition promoted by politicians, clearly an unadequate answer to the dynamics that turned the existing social hardship into social emergency.

In the former East Germany was recently planned the demolition of 350 000 vacant lodgings, in France is promoted the complete demolition of the “grands ensembles”, that means to pull down about 6 millions of lodgings in wich lives about 10 millions peoples. This initiative looks quite ambiguous as far as seems loaded of postmodernist preconceptions with a paradoxical reproposition of a new “tabula rasa”. Is easy to think that this trend could be driven by the politic’s interests about gaining general consensus and by the prospective of great economic results concerning the process of gentryfication of reconstructed areas.

Here we wants to say how important is to keep the footprint of both urban and human landscape with their memory and meanings. In this we see the capability of an urban “sustainability” for the inhabitants out of triviality of gentryfication conceived as treatment.

In such a context of heavy heritage, full of human matter, is hard to operate requalification following sustainability principles. In one hand having to deal with a complex social issue and in the other with structural and economic constraints. The goal of this kind of project is the implementation of the quality of life within the quality of spaces, joining the need to apply an adequate technology, in order to afford feasibility in the economic context. Following these principles all the design and all the intervention strategies were conceived to maximize performance and minimize costs. All the variations for the modular enclosure panels were designed to obtain difference with minimal change, always related to industrial production.

In the same way the internal modifications where minimized within the costs. On the façade only energy saving/gain solutions were used (insulation, Trombe-wall, greenhouses, wide glasses), on the roof energetic gain with thermosolar panels integrates existing facilities. The guide lines of the design project where to avoid to design special components, to provide only manual setting systems, to employ only standard technology (easy to found in future and easy to replace), and to apply easy maintenance design. The LCA would be included in further material design for the solutions process.

This use of standard conponents and save/gain-energy technology aims to partially absorb the cost of the new rent after the refurbishment, following the idea of keeping the actual users (that in the greater part are subsidy aided) after the refurbishment.

Out of general considerations about typical problems of ’60 mass housing, the project intends to turn off the concepts of “Block-barrier-Dam-Plattenbau-Unity-Equality” (that comes from social and urban analysis) into “Complexity-Multiplicity-Variety-Difference-Identity”. In this way the project act on different scales with an increasing strategy and the fundamental collaboration of the users (is important to remember the Kreuzberg experience on partecipated requalification in the ’80). In conclusion the goal of this kind of requalification would be the offer to the district’s people a scenario of opportunity of change, with the perspective of a better conditions where to live.

Sustainable management of buildings

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ABSTRACT: Building maintenance is a significant element of sustainable building. Careful maintenance enables to maintain the existing built environment, its economic value and the related cultural heritage; it helps to minimise material resource consumption, and supports the development towards improved energy efficiency.

Knowledge management methods should be developed to enable the optimisation of maintenance measures. Optimisation aims at the minimisation of maintenance costs and environmental impacts while ensuring that the required building performance is not hazarded. The most beneficial maintenance strategy can be determined by comparing the alternative maintenance profiles.

VTT has developed a life-cycle design model for buildings that can be described with the following terms: predictive, life-cycle based, optimising, and integrated. Owners and designers can use the model for the strategic management of building maintenance.

The paper summarises the results from the research project and discusses the meaning of maintenance management of buildings with reference to sustainable building.

1 INTRODUCTION

In addition to building design and construction also maintenance management significantly affects the building performance. The type, scale and timing of maintenance measures influence the building performance and thus also the life-cycle (LC) costs and profitability of real estates, and the comfort and productivity of the users of buildings.

Building maintenance is a significant element of sustainable building. With help of careful and systematic building maintenance it is possible to affect

- maintaining the existing built environment and related cultural value,
- economic value of constructive assets,
- consumption of material resource consumption, and
- energy efficiency.

Durability assessment and life cycle costing (LCC) are knowledge-intensive processes as stated by Ugwu et al. (2005). Durability assessment and service life design require that careful consideration is given to a range of issues that affect the design life of structures. Thus computer programmes should be developed in order to be able to compare and optimise alternative maintenance measures and the timing of these measures. Optimisation aims at the minimisation of maintenance costs while ensuring that the required building performance is maintained. With help of such optimisation programme, it is possible to determine the most beneficial maintenance strategy by comparing the alternative maintenance profiles.

VTT has developed procedures and tools for service life prediction, service life design and building maintenance management. The research has resulted in the development of a life-cycle design model for buildings - the so-called MAINTENANCEMAN tool - with the focus on exterior walls, balconies and roofs. Owners and designers can use and implement this model for the strategic management of building maintenance.

This paper summarises the results from this research project and discusses the meaning of maintenance management of buildings with reference to sustainable building. Chapter 2 of this paper presents the objectives and premise of the research project that developed the first version of the maintenance management tool. Chapter 3 discusses the significance of maintenance management from the view point of sustainable building. Chapter 4 introduces the main characteristics of the MAINTENANCEMAN tool, and Chapter 5 summarises the results.

2 RESEARCH PREMISE FOR THE DEVELOPMENT OF THE MAINTENANCE MANAGEMENT TOOL

VTT has developed procedures and tools for service life prediction, service life design and building maintenance management. The objectives of the latest research project were as follows:

- to describe a generic life cycle design model for the strategic maintenance management of buildings,
- to apply this approach for exterior walls and roofs from the view points of service life, life cycle costs and environmental impacts,
- to describe the connection of these models with the new methods of information management in building maintenance.

The premises of the research were as follows: 1) Building maintenance management is an essential element in the processes of sustainable construction and sustainable building. 2) Planning for service life and maintenance is important to improve LC management of buildings and built environment. 3) The management systems have to be based on predicted data and enable the improvement of the predicted data continuously during the process.

The optimisation requires that

- deterioration of structures can be described as age-depended,
- alternative maintenance measures and the limit conditions for those measures can be defined,
- the effect of maintenance measures on the condition and technical performance of structures can be assessed and determined and
- costs and/or environmental impacts from maintenance measures can be determined.

LC design approach enables the comparison of the costs during a certain time period from alternative maintenance profiles. These maintenance profiles are called here as alternative maintenance strategies. The alternative maintenance profiles may include different kinds of measures of renewals and repair. These measures may either prevent or delay deterioration, and there may be different time periods between the measures.

The risks should be taken into account as limiting factors. These can be defined on the bases of requirements concerning safety, appearance or other performance aspects.

3 SUSTAINABLE BUILDING AND MAINTENANCE MANAGEMENT

3.1 *Sustainable building methods*

Sustainable building research has focused on the development of assessment methods and indicators. In this paper the following methods are included as sustainable building methods:

- sustainability indicators for buildings and built environment.
- environmental classification methods of buildings (rating systems)
- life-cycle assessment (LCA) methods and life-cycle costing (LCC) assessment methods
- assessment methods of energy efficiency of buildings
- service life prediction methods.

In the discussions on sustainable building the link of sustainable building with building performance has been emphasised lately (Trinius and Sjöström 2005). Though environmental impacts and LC costs indicate aspects of sustainability, the quantifying and comparing cannot be done without a common reference. When comparing different design options, performance aspects are the underlying factor. As building performance is gaining stronger consideration in the connection of sustainable building, it also emphasises the maintaining the desired building performance as an important aspect of sustainable building process.

AEC sector needs LC guides and sustainable construction methods for requirement setting, design for required performance and life cycle, and declaration of LC quality of final products (Häkkinen and Pulakka 2007). According to Shelbourn et al. (2006) one of the key issues in making construction projects more sustainable is overcoming the obstacles of capturing and managing the knowledge needed by project teams to affect such change. Although indicators, checklists and assessment tools for sustainability in construction are available, there is still a need for a structured approach for the implementation of sustainability practices and methods within construction projects. From the viewpoint of the usability of LC methods, the most problematic field seem to be the design phase. Classification systems of sustainable buildings may support designers to consider LC aspects. LC assessment tools support designers to compare alternative solutions. Energy consumption estimation methods and service-life prediction methods support designers to identify and consider issues that affect energy efficiency and service life of design options. However, the classification methods only support designers with help of basic guidelines and the assessment methods bring much extra work for the design process. Design for sustainable buildings needs integrated methods that provide the process with easy-to-use product information and integrated calculation, optimisation and simulation facilities that enable the comparison of design options automatically or with reasonable extra work. Product model based building (BIM) will probably partly solve these problems as illustrated for example in Häkkinen (2007) from the view point of product information and in Lam et al. (2004) from the view point of simulation. The lack of powerful methods for sustainable building design concerns not only new buildings but largely also design for sustainable management of buildings.

According to Kohler and Lützkendorf (2002) the crucial issues for design tools include their scope, the number of performance aspects simultaneously addressed and the degree of integration into the usual design environment (e.g. through sharing data with other design tools). They refer tools of this type as integrated building LCA.

3.2 *Significance of sustainable building and sustainable maintenance management*

The implementation of the principles of sustainable development is a fundamental goal of EU policies (EU 2006). The renewed sustainable development strategy recognises the need to gradually change the current unsustainable consumption and production patterns. Sustainable communities should be able to manage and use resources efficiently and to make use of the innovation potential of the economy, ensuring prosperity, environmental protection and social cohesion.

The communication “Towards a Thematic Strategy on Urban Environment” (TSUE 2004) explains the priority theme Sustainable Construction by stating that “buildings and the built environment are the defining elements of the urban environment. They give a town and city its character and landmarks that create a sense of place and identity, and can make towns and cities attractive places where people like to live and work.”

Within the TSUE process the WG on Sustainable Construction (Sustainable Construction 2004) summarised that "The built environment represents a substantial and relatively stable environmental resource. Most buildings survive for several decades, and very many survive for centuries. As the community's principal physical asset, getting good value requires that the building's full life cycle is considered, avoiding short-sighted attempts to merely minimise initial cost. A strategy on sustainable development will seek to prolong the life of existing structures, and indeed to prolong the utilisation of the materials with which they were originally constructed. Adaptation is usually preferable to new building, and upgrading of performance often represents an efficient deployment of resources."

Sustainable construction technologies have a great potential with regard to overall environmental effects. The building sector is responsible for about 40% of Europe’s total primary energy consumption (Petersdorff et al. 2004). Environmental management of buildings and construction will be an important issue for the European Union in order to reach targets required by the Kyoto Agreement (EC 2006) and the higher targets agreed recently by the European environment ministers (EU 2007).

As shown in several studies and summarised for example by Petersdorff et al. (2004) the main energy and CO_2 saving potential lies in the existing building stock. Newly built houses are generally already built in compliance with national performance standards and therefore exhibit inherently small savings potential in CO_2 emissions. The demolition rate in the building stock can be estimated to be approx. 0.5-1 %. New building activity can be assumed to be 1% of the total living area per year thus resulting in a slight increase of the building stock (Petersdorff et al. 2004). As emphasised in the 3rd European Minister's Conference on sustainable housing, existing buildings must also be developed more sustainable by renovating those and ensuring that sustainability is a key consideration in their refurbishment and renovation. As much as 50% of all materials extracted from the earth’s crust are transformed into construction materials and products. As these materials enter the waste stream, those account for roughly 50% of all waste generated prior to recovery.

The LC approach can be distinguished in the two essential directives, which direct the building product and energy regulations of building, namely Construction Product Directive and Energy Performance Directive; both of these emphasise the importance of use phase of buildings. With regard to service life and maintenance planning, the Construction Product Directive is of importance (CPD 1988). According to the Annex 1 "the products must be suitable for construction works which (as a whole and in their separate parts) are fit for their intended use, account being taken of economy, and in this connection satisfy the essential requirements where the works are subject to regulations containing such requirements. Such requirements must, subject to normal maintenance, be satisfied for an economically reasonable working life."

The European TISSUE research project (Häkkinen et al. 2006, Häkkinen (ed.) 2007) analysed the sustainable urban construction related concerns (Table 1). The importance of refurbishment and renovation was emphasised from the view point of sustainable urban construction.

The results presented by Junnila and Horvath (2003) show that most of the environmental impacts in Finnish office buildings are associated with electricity use and building materials manufacturing - in particular, electricity used in lighting, HVAC systems, and outlets; heat conduction through the structures: manufacturing and maintenance of steel: manufacturing of concrete and paint, water use and waste water generation; and office waste management. Service life and maintenance planning have a remarkable effect on the choices that have significant environmental impacts.

The AEC sector still directs the main focus on new buildings. As stated by Kohler and Hassler (2002) the building stock play a minor role in the conscience of the architectural profession; their contemporary value system is still largely centred on the design of new buildings, as the principal objective and activity of architects and of engineers in general. Sustainable building and the related LC approach should move the focus from new building to building stock. New buildings should be built according to the principles of sustainable construction and the maintained as part of the existing building stock.

3.3 *Need of tools for sustainable maintenance management*

Especially the managers of municipal and state infrastructure are realising the need for effective tools to manage the large asset base. Decision support tools are needed in order to support understanding and decisions on its value, condition, remaining service life, needed maintenance and optimal scheduling of operations. According to Vanier (2001) few tools exist in the area of strategic asset management. Vanier (2001) states that there are several administrative, financial and technical challenges to fully address the need of municipal infrastructure planning: 1) data integration of the software environment, 2) enhancement and standardisation of the currently available tools, 3) central repository for the information, 4) shared experiences and best practices, 5) LC analysis and long term service life prediction, 6) intercommunication between municipal infrastructure research and the field of service life research. Although the article wrote by Vanier was published more that 5 years ago, these conclusions are still true in many respects.

Table 1. Development needs of sustainable urban construction indicators. Aspects of sustainable urban construction related concerns which should be monitored with help of indicators.

CONCERN	New indicators should be developed to enable the monitoring of...
Environmental pollution and consumption of resources	Efficiency of maintenance of buildings
Health and comfort	Indoor climate of buildings
Ageing/Disabled and other special groups of users of buildings	Barrier-free access to buildings and built environment
Availability of housing and buildings	Fulfilment of basic needs of housing for all
Business environment, productivity	Development of new client oriented services
	Exploitation of IC technological challenges
Age of building stock	Efficiency of refurbishment and renovation

Lounis and Vanier (2000) propose a multi-objective and stochastic system that integrates probabilistic performance-prediction and risk-assessment models with optimisation approach for roofing maintenance management. Discrete Markov chains are used to model the performance of roofing components that account for their time dependence and uncertainty.

Söderqvist and Vesikari (2006) described a predictive, optimising and integrated LC management process. The system makes it possible to organise and implement all the activities related to maintaining, repairing, rehabilitating and replacing of assets in an optimised way taking into account all necessary aspects of LC planning, i.e. LC costs, LC ecology, LC performance.

Bucher and Frangopol (2006) introduce a method for optimisation of lifetime maintenance strategies for deteriorating structures considering probabilities of violating safety, condition, and cost thresholds. While modern maintenance strategies for deteriorating structures typically are based on minimising total cost, the extension of this concept into the non-deterministic range allow to take into account the uncertainty in total cost. In the method described by Bucher and Frangopol (2006), the probability of exceeding a total cost threshold is included in the maintenance optimisation problem. In addition, the probabilities of violating acceptable levels of safety and condition are calculated. Based on this, an optimisation task can be formulated and solved by including these probabilities into the formulation of the objective function and the constraint conditions.

The use LCC in building sector has remained limited. Reasons include a general lack of motivation to use LCC, methodological problems, non-access to reliable data, and practical problems faced by building practitioners as presented by Cole and Sterner (2000). However, by including the LCC data into optimisation tools and thus enabling the use of LCC as a decision criterion for optimal maintenance schedules and solutions, it is possible to avoid many of the stated problems.

3.4 *Significance of maintenance from the view point of life-cycle costs*

VTT has studied the life-cycle cost significance of maintenance management in the cooperation with the Finnish Senate Properties. Senate Properties is a government owned enterprise that is responsible for managing the Finnish state's property assets and for letting premises. The building stock comprises university, office, research, cultural and other buildings (Senate Properties 2006). Table 2 introduces an estimation of typical life cycle costs concerning a typical office building in southern Finland. The estimation considers the foreseeable real increase of energy expenses (+3%/a).

Table 2. Life cycle costs concerning a typical office building in southern Finland. Estimation.

Lice cycle	Capital cost	Care	Maintenance and refurbishment	Heat energy	Electricity	Other costs	Total costs
50	18	3	18	4	6	5	54

According to Pulakka et al. (2007) a forthcoming refurbishment may cause a delay for executing of the needed maintenance measures. Also short tenancies may delay the maintenance measures until the end of the tenancy. The share of costs of care from LC costs is rather small, but neglecting may significantly affect user satisfaction, productivity and health of users. Proactive care aims at avoiding the costs that become from the repair of damaged components and building parts. The share of damage costs from LC costs (with regard to 50 years' time period) is typically around 5%. The share is the higher the more proactive care and maintenance is neglected. When planning and proactive maintenance is failed, the share of maintenance and refurbishment may be very remarkable with regard to the total costs.

4 MAIN FUNCTIONS OF THE MAINTENANCEMAN TOOL

The MAINTENANCEMAN project described the comprehensive maintenance management process and developed a tool with help of which the alternative maintenance profiles can be defined and assessed in terms of LC costs and environmental impacts. The tool is a prototype version.

Figure 1 shows the structure of the described LC management system. The process starts from the definition and inspection of structures and ends in the determination and execution of projects. Between the start and the end of the process, the system produces project plans in three phases: 1) action planning, 2) project planning, and 3) annual project and resources planning.

In the course of all these phases, initial and updated data for the building, its structural parts, and actions of maintenance and repair are needed. These data come from a set of databases representing buildings, modules, and repair systems. Ideally there should be a link between the BIM and the tool. The building data is divided into modules which serve as the units for monitoring and inspection, analysis, design and execution of actions.

The MAINTENANCEMAN tool uses degradation, action effect, and cost models. The degration models are in the form of transition probability matrices. The transition probabilities tell the probability that the module is shifted from one condition state to another condition state because of degradation. The action effect models tell the effect of a repair action on the condition of the module. The transition probabilities tell the probability that the module is shifted as a result of the repair action to any of the condition states that is better than the original condition state. The cost models include the unit costs of the repair and rehabilitation systems. The costs are evaluated separately for each repair system and material alternative. The core of the tools is the analysis table which is a joint table of condition, LC cost, and environmental impact analyses. The condition analysis is based on the Markov Chain method by which the annual condition state distributions of modules are evaluated through the whole design period. With help of Markov Chain method the prediction of modules is changed from a deterministic to a stochastic analysis. The principle process is described in detail by Vesikari (2003).

As a result of the analysis process, lists of predicted actions are produced. These include repair, rehabilitation and maintenance actions for each module. The action data are obtained from the core analysis tables and transited to results tables by special macro routines. Another table is produced from damage repair actions. This table is made straight forward from the inspection data in the module database by another macro routine.

5 SUMMARY AND CONCLUSIONS

Sustainable building and construction is among the priorities of the European Union with reference to sustainable development and striving for stated targets. Achieving and maintaining the desired building performance while minimising the negative impacts in terms of environmental, economic and social aspects are the essential elements of sustainable building. Maintenance management is an important process both from the viewpoint of building performance and lifecycle impacts. Building maintenance management enables to maintain the existing built environment, its economic value and the related cultural heritage; it helps to minimise material resource consumption, and supports the development towards improved energy efficiency.

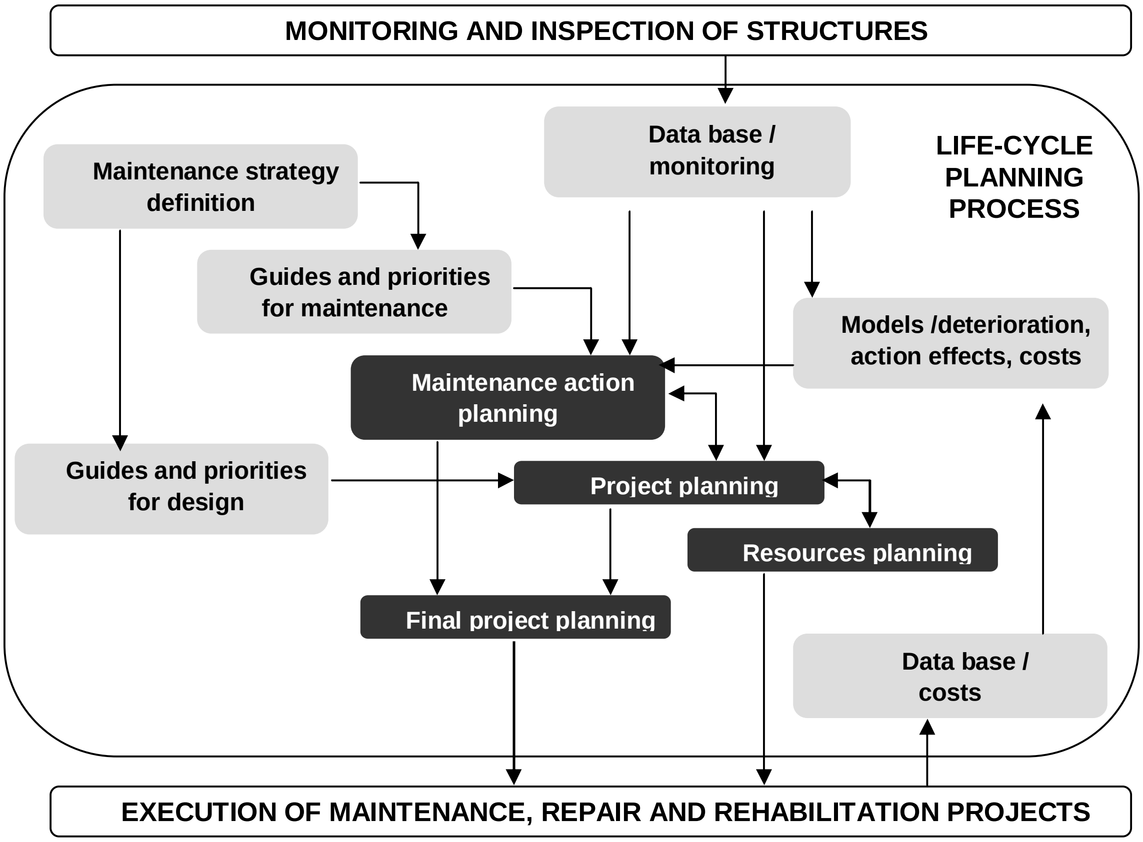

Figure 1. Life-cycle planning process.

Sustainable building research has focused on the development of assessment methods and indicators. AEC sector needs LC methods for requirement setting, design for required performance and life cycle, and declaration of life-cycle quality of final products. While methods for assessment and declaration are rather far developed, the AEC sector still needs powerful LC methods for design and strategic maintenance management. Design for sustainable buildings and building maintenance needs integrated methods that provide the processes with facilities that enable the comparison and optimisation of design and maintenance options. The lack of effective methods for sustainable building design concerns not only new buildings but largely also design for sustainable management of buildings.

The importance of maintenance management from the viewpoint of sustainable building is also emphasised because of its remarkable share from LCC, because of its potential effects on improved energy-efficiency and because of the significance of existing building stock compared to the new buildings constructed yearly.

Design for service life and maintenance management is a knowledge-intensive process which demands that consideration must be given to a range of issues that affect the durability, service life and care and maintenance of structures and building services systems. In order to manage the challenges, building information models and maintenance management tools have to be developed.

VTT has developed a maintenance management tool. Owners and designers can use and implement this model and tool for the strategic management of building maintenance considering both life-cycle costs and environmental impacts. The current tool is developed with the focus on exterior walls, roofs and balconies, but the concept and the development of the tool should go on in order to cover the whole building. The tool should also be developed so that it enables the strategic planning for improved energy-efficiency. The building information models should be developed so that the starting values needed in the use of the tool would be directly available.

REFERENCES

Bucher, Christian, & Frangopol, Dan M. 2006. Optimization of lifetime maintenance strategies for deteriorating structures considering probabilities of violating safety, condition, and cost thresholds. Probabilistic engineering Mechanics 21 (2006). Pp. 1 - 8

Cole, Raymond, J. & Sterner, Eva. 2000. Reconciling theory and practice of life-cycle costing. Building Research and Information (2000) 28(5/6), pp. 368 - 375

EC 2006. European climate change programme. In: http://ec.europa.eu/environment/climat/eccp.htm

EU 2006. Europe, European Commission, Environment, Policies, sustainable development. http://ec.europa.eu/environment/eussd/

EU (2007) Press release, 2785th Council Meeting. Environment Brussels, 20 February 2007. 6272/07 (Press 25) In: http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/envir/92864.pdf

Häkkinen, Tarja, Rauhala, Kari and Huovila, Pekka 2006. Indicators and criteria for sustainable built environment (In Finnish with English abstract). VTT Research Notes 2325. VTT, Espoo. 89 p. + App. 29 p. http://www.vtt.fi/inf/pdf/tiedotteet/2006/T2325.pdf

Häkkinen, Tarja 2007. Sustainable building related new demands for product information and product model based design. ITcon Vol. 12, pg. 19-37

Häkkinen, Tarja & Pulakka, Sakari. 2007. Use of LC guides in open building manufacturing. In: Open Building Manufacturing: Core Concepts and Industrial Requirements. Ed. Katzi, Sami.

Häkkinen, Tarja ed. 2007. Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment. Final Report. Summary and recommendations. VTT Publications. Espoo 2007. 234 p. + App. 53 p.

Junnila, Seppo and Horvath Arpad. 2003. Journal of infrastructure systems. December 2003, pp. 157 - 166

Kohler, Niklaus & Hassler, Uta (2002) The building stock as a research object. Building research and information 30(4), 226 - 236

Kohler, Niklaus & Lützkendorf, Thomas. 2002. Integrated life-cycle analysis. Building Research & Information (2002), 30(5), 338 - 348.

Lam, K.P., Wong, N.H., Mahdavi, A., Chan, K.K. Kang, Z. and Gupta, S. SEMPER II: an internet based multi-domain building performance simulation environment for early design support. Automation in construction. Vol. 13. pg. 651 - 663

Lounis, S. & Vanier D.J. 2000. A multiobjective and stochastic system for building maintenance management. Computer aided civil and infrastructure engineering. 15 (2000), pp. 320 - 329

Petersdorff, Carsten, Boermans, Thomas, Stobbe, Ole, Joosen, Suzanne, Graus, Wina, Mikkers, Erwin and Harnisch, Jochen. Mitigation of CO2 emissions from building stock. Beyond the EU Directive on the Energy Performance of Buildings. Report established by ECOFYS for EURIMA & EuroACE. 2004. 40 p.

Pulakka, Sakari, Junnonen, Juha-Matti and Heimonen, Ismo 2007. Life cytcle costs of building services (In Finnish with English abstract). Manuscript 15.5.2007. VTT Espoo

Senate Properties 2006. Business and organisation. In: http://www.senaatti.com/index.asp?siteID=2

Shelbourn M A, Bouchlaghem D M, Anumba C J, Carillo P M, Khalfan M M K and Glass J (2006) Managing knowledge in the context of sustainable construction, ITcon Vol. 11, pg. 57-71

Sustainable Construction 2004. Working Group Sustainable Construction; Method & Techniques. October 2003. Contract B4-3050/2003/352567/SER/B4

Söderqvist, M. and Vesikari, E. 2006. Life Cycle Management Process. In: Predictive and Optimised Life Cycle Management. Buildings and Infrastructures. Chapter 5. Taylor and Frances. ss.530-635.

Trinius, Wolfram & Sjöström, Christer. 2005. Service life planning and performance requirements. Building research & information. Vol. 33. pg. 173 - 181

TSUE 2004. Communication from the Commission to the council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions. Towards a thematic strategy on the urban environment. Brussels, 11.02.2004. COM(2004)60 final.

Vanier, D.J. 2001. Why industry needs asset management tools. Journal of computing in civil engineering. Vol 15, no. 1, Jan. 2001, pp. 35 - 43

Vesikari Erkki 2003. Statistical Condition Management and Financial Optimisation in Lifetime Management of Structures. *Lifecon GIRD-CT-2000-00378 Lifecon Deliverable D2.2,* final report. http://lifecon.vtt.fi/

Ugwu, O.O., Kumaraswamy, M.M., Kung, F. and Ng, S.T. 2005. Object-oriented framework for durability assessment and life cycle costing of highway bridges. Automation in construction. Vol. 14. Issue 5. pg. 611 - 632

Effect of Balcony Glazing on the Durability of Concrete Structures in Nordic Climate

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ABSTRACT: Degradation of concrete structures cause globally a huge repair need. Reduction of the moisture exposure of concrete structures is one potential way to prolong the service-life of them because the progress of all the major degradation mechanisms, such as reinforcement corrosion and disintegration, require high moisture content in concrete. This paper describes a research project where the efficiency of a balcony glazing to decrease the moisture exposure of balconies was studied experimentally in three apartment blocks in Finland. The efficiency of the moisture protection by the glazing was measured by monitoring the corrosion rate of reinforcement in carbonated concrete sensors which were installed both in glazed and open balconies. The results showed that glazing changes the micro-climate in the balcony so that the hygrothermal conditions turned unfavourable to degradation resulting in remarkable increase in service-life of concrete structures.

1 INTRODUCTION

Deterioration of concrete structures may lead to extensive repairs causing large direct and indirect costs, use of both energy and non-renewable natural resources. There are many factors leading to repairs, but by far the most part of repair needs is known to result from reinforcement corrosion and disintegration of concrete.

To avoid massive repairs it is sensible to try to protect structures from deterioration. This means application of measures that change the conditions inside the structure unfavourable for one or more deterioration mechanisms. It is important that the measures that protect a structure from one deterioration mechanism do not change conditions so that some other mechanism will be accelerated harmfully.

There are several potential ways to protect concrete structures. However, the proven protective treatments, such as cathodic protection and over-cladding with additional thermal insulation, are very expensive to apply. This concerns especially those structures which are most potential for preventative measures, i.e. structures which are still without major visual signs of damage despite that there are serious deterioration processes proceeding inside the structure.

From the protection point of view it is important to notice that all the major deterioration mechanisms are strictly controlled by the presence of moisture. For example, carbonation induced corrosion is known to proceed only above 80 % relative humidity (Alonso et al. 1988, Tuutti 1982). The disintegration of concrete due to freeze thaw exposure or ASR requires moisture content of concrete close to the saturation state [Pigeon & Pleau 1995, Hobbs 1988).

The fact that deterioration needs a lot of moisture offers a simple way to protect structures by lowering their moisture content. However, the utilisation of this principle in practice is problematic because the efficiency and performance of these types of measures has usually not been proven.

A balcony glazing is one potential way to control the moisture exposure of balconies both in new construction production as well as in renovation (see Figure 1). Balcony glazing has been in use in Finland since the middle of 1980's. At that time the reason for installation of glazing was purely to increase the usability of the balcony space. As the balcony glazing become more common in 1990's it was noticed that the surfaces inside the glazed balconies were kept in better shape than in traditional open balconies. This connected with the knowledge about the positive effect of decreased moisture exposure on the deterioration of concrete structures gave an impulse to study the effect of balcony glazing on the durability and service-life of balconies constructed of reinforced concrete.

Figure 1. Balconies made of reinforced concrete and outfitted with glazing.

2 PROTECTION FROM MOISTURE BY BALCONY GLAZING

As stated already earlier in this paper, deterioration of concrete structures requires a lot of moisture. The corrosion of steel reinforcement in carbonated or chloride contaminated concrete is fastest when concrete is partially saturated with water (Alonso et al. 1988). On the other hand, the disintegration of concrete by freeze-thaw exposure requires that there is so much moisture in the concrete that there is not enough air-filled pore space in concrete for the volume expansion of the freezing water to discharge without causing physical damage. (Pigeon & Pleau 1995).

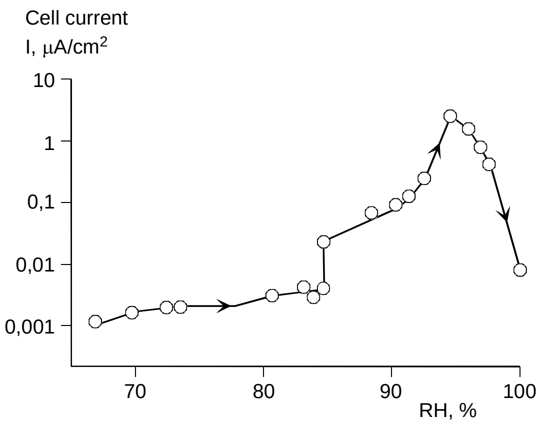

Figure 2. Relationship between cell current and relative humidity according to (Tuutti 1982).

From Figure 2 it can be seen that if the relative humidity of reinforced concrete can be lowered down to 90 % of relative humidity or less, the corrosion rate may decrease up to 90 % (Tuutti 1982). What comes to the potential acceleration of carbonation due to drying of concrete (Parrott 1987), it is important to notice that increased moisture content may retard carbonation only by some tens of percents, but the same change may multiply the corrosion rate. Also from the experience it is known that corrosion damage due to carbonation has not usually occurred in those parts of structures where the moisture exposure has been lowest and carbonation quickest, but just the opposite.

The main function of a balcony glazing in Nordic climate is to keep rainwater, snow and dust away from a balcony and the warmth inside it so that it is more convenient to use. For this purpose glazing is always equipped with such flashings etc. that prevent rainwater from leaking in through the joints etc. It is also found that glazing should not be too air-tight to enable sufficient ventilation to demist the glazing in certain climatic conditions. Because of this, glazing is most usually composed of adjacent cageless glass panes with interstices of few millimetres between them. This has been found to ensure sufficient ventilation. The drainage of glazed balconies is usually arranged by internal piping.

It is obvious that balcony glazing will not affect the moisture exposure only by preventing the moisture get inside the balcony but also by creating such micro-climate that promotes drying. The solar radiation as well as the thermal flux through the external wall or a window behind the balcony most probably raises the temperature inside the balcony, which increases the saturation deficit and will probably further lower the moisture content of concrete.

3 EXPERIMENTAL

3.1 General aspects

The evaluation of the efficiency of balcony glazing to lower the moisture load and moisture content of concrete structures is a complicated problem. Apparently, the impact seems to be positive, but it is impossible to evaluate this quantitatively without measurement data from representative structures and conditions.

One potential way to evaluate the performance of balcony glazing to lower the moisture content of concrete is to monitor the moisture content of concrete by electronic devices. This is, however, scientifically unsound method because of two reasons. Firstly, the accuracy of the electronic moisture measurement is not very high. For example, the corrosion rate of reinforcement in carbonated concrete may vary even more than one decade within the incremental sensitivity of the best devices on market. The moisture meters also operate on the hygroscopic area only, whereas deterioration is known to be fastest in partially saturated concrete, i.e. at the super-hygroscopic moisture range (Alonso et al, 1988). This is why the performance of balcony glazing to reduce deterioration rate cannot be studied reliably by measuring moisture unless the decrease of the moisture content is systematic and very large.

A potential mean to pass the problems with the moisture measurement is to measure the rate of deterioration itself. The are not available feasible instruments for the NDT monitoring of disintegration processes so far, but the corrosion rate of embedded steel bars can be monitored relatively simply for example by polarization resistance method (Stern & Geary 1957). This is a sensible way to get a quantitative picture of the protective effect of balcony glazing because corrosion is controlled mainly by ambient moisture and temperature.

3.2 Monitoring method and apparatus

A tailor-made device for the monitoring of corrosion rate of steel in concrete was prepared for this purpose. The device uses polarisation resistance technique to measure the instantaneous corrosion rates (Stern & Geary 1957). The cumulative corrosion attack can be calculated easily from this data.

The device utilises modern computer technology so that steel potential is directly controlled by a computer without a potentiostat. The device is fully automatic to perform continuous monitoring of corrosion rates and equipped with mobile data connection to fetch the data from field sites to the university campus. The device can deal with a maximum of 120 measurement channels and it is described in more detail in (Mattila 2003).

An important point to consider is that should the data be gathered from field or is it possible to get representative data from laboratory tests. In this study, laboratory tests were excluded because the moisture exposure in outdoor concrete structures cannot be simulated very accurately in laboratory. The reason for this is that all the parameters determining the microclimate inside a balcony, which determines the rate of degradation, cannot be predicted accurately enough.

Because the moisture conditions of real structures under climatic exposure are in a continuous state of change, data is gathered by the device frequently to catch also short-term phenomena.

3.3 Sensors

For the monitoring purposes, special sensors were prepared and mounted into balconies of existing buildings (see Figure 3). The sensors contain reinforcement bars and suitable electrodes for the monitoring of corrosion rate by polarisation resistance technique.

The reason to use the sensors was to get uniform concrete quality for all the monitoring points. In this case the variation of concrete quality in different field test buildings and measuring points can not cause bias in the results. Another point was to have to possibility to make sure that all the reinforcement bars are positively in active corrosion in carbonated zone by accelerated carbonation. In this case the corrosion rate in the sensors will reflect the change in hygrothermal conditions achieved by balcony glazing and gives a reliable picture of the possible retardation of deterioration. As a by product, information of the risk of progressing frost damage will be got as well, because the critical moisture content required for this can be recognised from high corrosion rates.

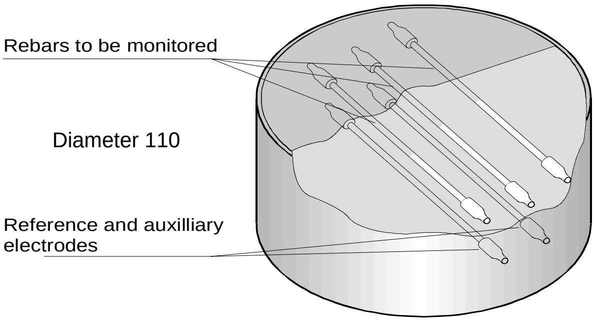

Figure 3. Schematic diagram of the sensor used.

The composition of the concrete used in the sensors was selected so that the concrete would be as similar as possible to the aged concretes used in concrete facades in Finland during 1960's and 1970's. The cubic strength of the concrete was 25 MPa.

The diameter of sensors was 110 mm and thickness 60 mm. The steel bars were ordinary cold drawn reinforcement with the diameter of 4 mm and nominal yield strength of 500 MPa.

After casting and 28 days of curing in 40 °C water (to achieve high degree of hydration as in old structures), the sensors were exposed to accelerated carbonation in 4 % carbon dioxide according to (Dunster 2000) until carbonation has reached all the studied bars.

The sensors were coated with permeable silicate paint for aesthetic reasons. The coating is totally open for both liquid water and water vapour so that sensors will represent also uncoated concrete.

Sensors were mounted in the balconies of three residential blocks, of which two were located in Tampere (exposed to Finnish midland climate) and one in Espoo near to the south coast of Finland (exposed to more severe coastal climate). All the instrumented balconies were facing south or west.

Altogether 14 sensors were installed in each building. One half of this was installed in glazed balconies and another half in open balconies for reference. In both group, six sensors were installed in the side walls and one on the ceiling.

The sensors in the walls were mounted into holes drilled through side walls of balconies (see Figure 4). The gap between the sensors and the hole was sealed with elastic polyurethane sealant to prevent the leakage of water into the structure. In addition, the envelope surfaces of the sensor cylinders were sealed with aluminium adhesive tape to prevent the moisture transfer between the sensor and the concrete of the outer panel so that the performance of the old coating on the concrete surface surrounding the sensor would not have an influence on the moisture stress of the sensors. The sensors on the ceiling were mounted below the ceiling.

A part of the sensors were equipped with temperature transducer so that the temperatures of the balcony structures could be monitored as well.

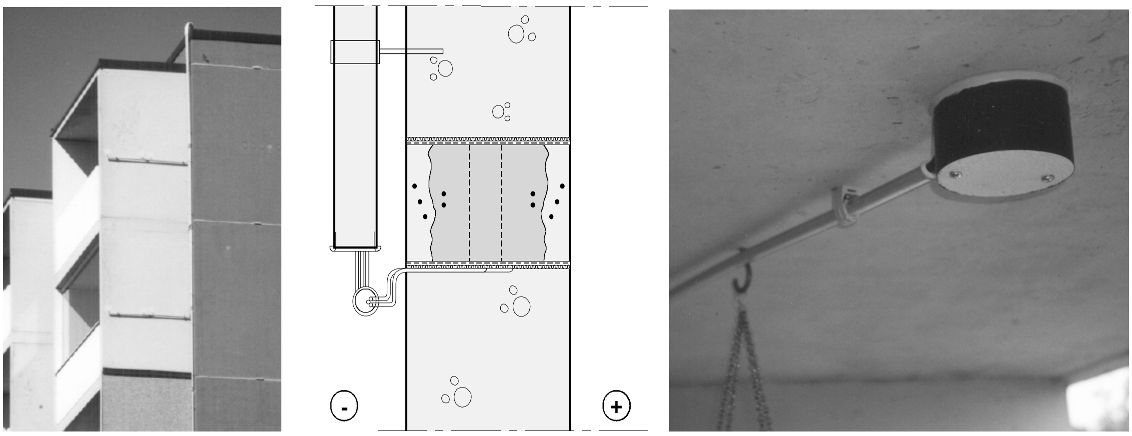

Figure 4. Pictures showing the principle of the installation of sensors into the structures. On the left: Glazed and open reference balcony. The sensors in the side walls are installed in the middle height of the wall panel. In the middle: Vertical cross-section of the sensors mounted into a hole drilled to a side wall. On the right: A sensor installed on the lower surface of the slab.

The installation of the sensors took place in the summer 2000 and the monitoring system was installed during the autumn 2000. The collection of the corrosion rate data was started from the beginning of December 2000 and it was stopped at the end of year 2002.

4 RESULTS AND DISCUSSION

The efficiency of the balcony glazing to retard deterioration was evaluated by monitoring the corrosion rate of reinforcing bars in carbonated concrete, both in glazed and open balconies. The quantity measured by the monitoring system is the instantaneous corrosion current [µA/cm2]. The data was converted to cumulative radius loss of steel section in µm (i.e. depth of corrosion attack) by integrating the corrosion currents over time and applying the Faraday's law.

The cumulative radius losses calculated from the monitoring results from the 25 month monitoring period are presented in Figure 5. The results were very uniform in all the three buildings. This is the results are not presented separately, building by building.

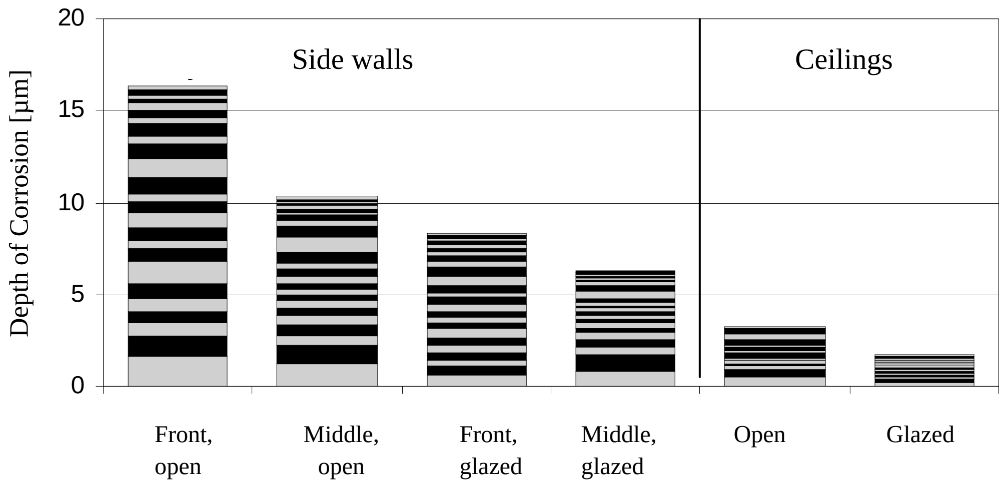

Figure 5. Average cumulative radius losses of steel sections in three buildings in the 25 month monitoring period.

The sections of each bar in the figure represent the monthly values of radius loss so that the bottom section of each bar represents the radius loss measured in the first monitored month, i.e., Dec. 2000, and the uppermost section represents the last monitored month, i.e., Dec. 2002. All the sections are not distinguishable because of the exiguity of the monthly corrosion.

From Fig. 5 it can be observed that balcony glazing decreased the corrosion rate of steel in concrete clearly and systematically. The reduction over the monitoring period was roughly 30 to 50 % in the side walls and 50 % in slabs.

To evaluate the measured quantities (radius losses), results from (Alonso et al 1998, Andrade et al 1993) can be used as a guideline. According to these, an average radius loss of 50 µm is required to cause the first visible crack (0.05-0.1 mm) in the cover concrete when the cover depth is relatively small. On the basis of this it can be calculated coarsely, what will be the duration of the active corrosion phase before cracking in studied structures. The results from this calculation are presented in Table 1.

Table 1. Average yearly corrosion depths and calculated durations of the active corrosion in glazed and open balconies.

	Balcony side walls		Ceiling surfaces	
	Glazed	Open	Glazed	Open
Average yearly corrosion depth during the monitoring period [µm]	4	7	1	2
Calculated duration of the active corrosion [a]	12	7	50	25

From Table 1 it can be noticed that increase in the service-life of the structures can be significant. From the viewpoint of lifespan of a building, fro example one decade is not a significant period, but from financial point of view it is a remarkable prolongation in service-life.

It is worthwhile to notice especially the low corrosion rates in the ceiling surfaces. The calculatory duration of active corrosion will be about 25 years even in open balcony and this can be doubled by glazing. This is an important finding because there are often low cover depths and deeply penetrated carbonation on the ceiling surfaces. These results show that that kind of struc-

ture may have residual service-life of decades left without any major repair measures. This naturally requires that the waterproofing of the upper floor is kept in a good shape.
The temperature of concrete was also monitored once an hour at the same spots as corrosion was measured. The recorded temperatures were processed to monthly averages in glazed and open reference balconies. The monthly differences in temperatures between glazed and open balconies were calculated and presented in Figure 6. The positive difference means that temperature was higher in glazed balconies.

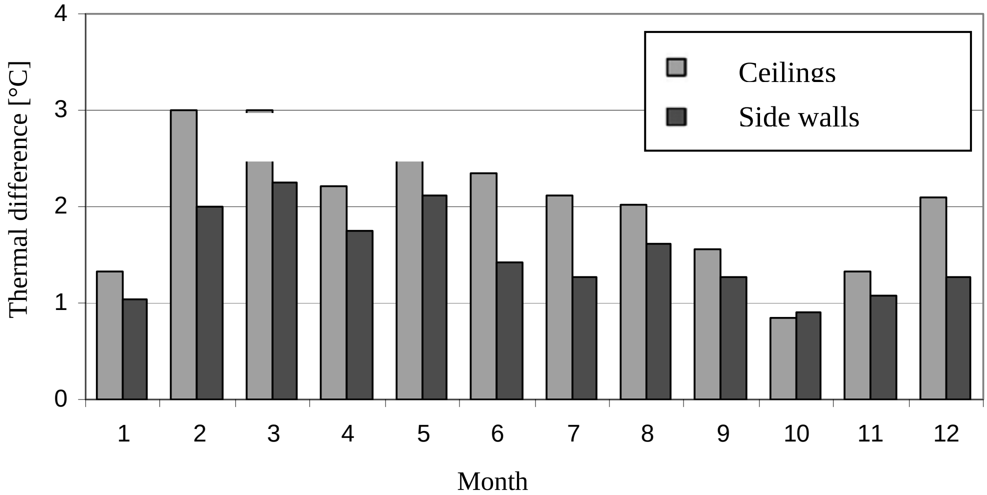

Figure 6. The difference of monthly average temperatures in glazed and open reference balconies. The positive difference represents the situation that that temperature has been higher in glazed balconies.

From the average temperatures in Figure 6 it can be seen that temperatures are systematically higher in glazed balconies. In the half height of side walls the temperatures were in average about 1.5 °C and in the ceilings in average about 2 °C higher in glazed balconies compared to open reference balconies practically throughout the year. This temperature difference prevailed even during the cold season when the solar radiation is very weak.

This apparently small difference in the temperatures can be regarded as important because it increases the saturation deficit and therefore promotes the drying of concrete.

To evaluate the risk of frost damage on the basis of corrosion rate data, the single corrosion rate measurements were plotted against the temperature of concrete at the moment of the corrosion rate measurement. This plot is presented in Figure 7.

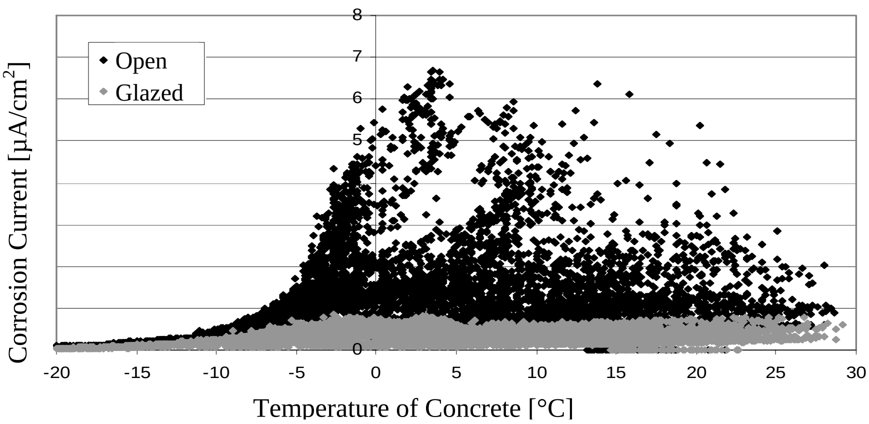

Figure 7. Instantaneous corrosion currents plotted against the temperature of the concrete at the moment of corrosion rate measurement.

From Figure 7 it can be observed that corrosion rates in glazed balconies remain permanently below 1 μA/cm^2. When the progress of frost damage process requires almost full saturation, which means corrosion currents of at least 4 to 5 μA/cm^2, the plot proves that damage by freeze-thaw exposure is prevented by glazing.

When considering the reliability of the results it is important to notice that the results depend strongly on the climatic conditions, especially on the amount of liquid rainfall during the monitoring period. Because the period is only a little longer than two years, the conditions might not necessarily fully represent the long-term average conditions. However, on the basis of examination of the meteorological data from the monitoring period, it can be stated that the results seem not to be significantly distorted due to abnormal weather conditions.

5 CONCLUSIONS

The objective of this study was to evaluate the effect of balcony glazing on deterioration and service-life of concrete structures. Carbonation induced reinforcement corrosion and disintegration by freeze-thaw exposure were considered as main deterioration mechanisms.

The rate of deterioration was measured by monitoring the corrosion rate of steel in carbonated concrete sensors. On the basis of the results, the following conclusions may be drawn:
1) Balcony glazing prolongs the service-life of balconies made of reinforced concrete by reducing their moisture load and by raising their temperature and consequently enhancing their ability to dry out.
2) Because of this enhanced hygrothermal performance the service-life of the structure is prolonged against visual cracking due to active corrosion for about 5 years in side walls and for about 25 years in the bottom surface of the slabs. Especially the latter finding makes it possible to avoid useless and difficult patch repairs in the lower surfaces of the balcony slabs.
3) Conditions enabling the progress of frost damage were removed totally by the glazing totally.

REFERENCES

Alonso, C., Andrade, C. and González, J.A., 1988 'Relation between resistivity and corrosion rate of reinforcements in carbonated mortar made with several cement types', Cement and Concrete Research 8, 687 - 698

Tuutti, K., 1982 'Corrosion of steel in concrete', Swedish Cement and Concrete Research Institute CBI, Research 4:82. Stockholm

Pigeon, M. and Pleau, R., 1995 'Durability of Concrete in Cold Climates', E&FN Spon, Suffolk.

Hobbs, D. W., 1988 'Alkali-silica reaction in concrete', Telford.

Parrott, L.J., 1987 'A review of carbonation in reinforced concrete', Cement and Concrete Association, Wexham Springs.

Stern, M. and Geary, A.L. 1957 'Electrochemical polarization, I. A theoretical analysis of the shape of polarization curves', Journal of the Electrochemical Society, January 1957. 56 – 63

Mattila, J. and Pentti, M., 2003 'Control of active corrosion due to carbonation by moisture lowering techniques', Tampere University of Technology, Structural Engineering, Report 123. Tampere. (In Finnish).

Dunster, A.M., 2000 'Accelerated carbonation testing of concrete', Building Research Establishment. Information paper IP 20/00. Watford.

Alonso, C., Andrade, C., Rodriques, J. and Diez, J.M., 1998 'Factors controlling cracking of concrete affected by reinforcement corrosion', Materials and Structures 31, 435 – 441 .

Andrade, C., Alonso, C. and Molina, F.J., 1993 'Cover cracking as a function of bar corrosion: Part I - Experimental test', Materials and Structures. 26, 453 - 464.

TECHNICAL SOLUTIONS FOR SUSTAINABILITY IN POST-WAR RESIDENTIAL AREAS

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Abstract

In many countries, the existing housing stock will be a major part of the total stock for the coming hundred years or more. Thus, to reach urgent goals for sustainable building, it is necessary not just to develop better concepts of new building, but also new models for housing renovation and management. In Sweden, during the last decade, several environmentally oriented renovation projects have been realized in large housing areas built 1946-1975. Thorough studies of some fifty projects aiming at environmental sustainability, as well as social, economic and cultural, offer an overview of problems and technical solutions. The aim of this paper is to give a summary of this overwiew and to discuss the effects, efficiency, and applicability of specially interesting types of measures concerning building envelopes as well as technical systems and equipment, the outdoor environment, and social sustainability.

1 SUSTAINABLE RENOVATION – AN EXPANDING ENTERPRISE

The awareness of sustainability matters is constantly growing in the building sector. This is also true for rebuilding, and the need for models for sustainable housing renovation is urgent. In Sweden, almost half of the multifamily housing stock will need extensive renovation in the next 15-20 years. A majority of those dwellings are found in large housing areas built 1946-1975 where most sanitary and electrical systems have served their time, and many ventilation systems are ineffective. The thermal insulation of façades, windows, and roofs does not correspond to the requests of today, and many building envelopes need some kind of renovation. In addition, the common spaces indoors and outdoors, and many dwellings, may need upgrading or ordinary maintenance (Boverket 2003). This need for actions offers an exceptional opportunity to develop the general sustainability of the housing stock, by choosing the proper measures and tecnical solutions. It is not an easy task, though. Limited resources for maintenance and new investments, and uncertainty about the pros and cons of alternative technical solutions may put a break on the development. A special concern in Sweden is the requirement for care for the characteristics and values of the original building, prescribed by the Planning and Building Law since 1987. This requirement is in force for all renovation works, not just for building with special cultural or historical values, and may demand extra attention when renovation programmes are prepared.(Vidén & Botta 2006).

In the years 1998-2002 some fifty renovation projects concerning large housing areas, developed 1946-1975, were allocated governmental grants (LIP grants; LIP is short for Local Investment Programme) for a rich variety of environmental measures. Studies of these projects indicate what effects, costs and benefits those measures can involve, how different kinds of measures can be adapted to characteristics and qualities of the existing housing, and how they are accepted by the residents. Many examples and experiences of the technical solutions from those environmentally oriented projects offer models for the sustainable renovations to come.

The environmental measures can be distributed on groups according to their main direction:

- *Energy supply, energy saving*
  - Renewable sources for heating: bio energy, solar energy
  - Energy efficient heating and ventilation installations
  - Recovering heat from ventilation air
  - Individual measuring of heat, hot water and electricity consumption
  - Installation of energy saving electric equipment
  - Improved insulation of the building envelopes: façades, roofs, windows
- *Water saving and waste water treatment*
  - Installation of water saving equipment
  - Individual measuring of water consumption
  - Installation of urine sorting toilets (seldom practiced)
- *Sorting and recycling of refuse: domestic and building refuse*
  Composting of or disposers for biological refuse
  - "Environmental cottages" for sorting refuse
  - Sorting and recycling building refuse
  - Local recycling workshops
- *Promoting a healthy indoor climate, reduction of harmful materials*
  - Choosing healthy, and resource saving, materials for rebuilding
  - Limiting electric and magnetic radiation
  - Replacing harmful materials in the existing building
- *Improving the outdoor environment and biological diversity, rainwater treatment*
  - Increasing "green" surfaces and the diversity of plants
  - "Green" roofs, planting more, and big, trees
  - Local handling of rainwater
  - Allotment gardens, local nature conservation actions
- *Improving social life and accessibility for disabled persons*
  - Establishing local "environmental" teams, information actions
  - Establishing special meeting places for the neighbourhood
  - Adjusting the distribution of flats to local needs and demands
  - Facilitate permanent living for disabled persons

All these cathegories, apart from their main purpose, involve a mixture of environmental, economic, social and cultural effects, even the last one, mainly applying to social sustainability. Many of all those renovation measures promoting resource saving and recycling are already commonly used. This is true especially for measures which do not demand big investments and/or will have a pay-back time of just a few years. Such measures are necessary parts of the sustainability concept, but not focussed in this paper. The same is true for many other measures, which are more or less directed by local regulations and local conditions. In this paper, instead, the choice of examples is made to call attention to positive experiences of measures which may promote the housing and living conditions as a whole – the social and cultural sustainability as well as the environmental and economic sustainability.

2. ENERGY SAVING

2.1 Improvements of heating and ventilation systems, and electrical fittings

Energy saving is, in more than one aspect, the most favoured goal for sustainable renovation. Transitions to renewable energy sources for heating or electricity production are stimulated by national tax policies or grants, and, subsequently, biomass fuel is more and more used instead of oil. Many systems for direct electrical heating have been exchanged for biomass fuel systems, or others, especially in single family housing but some in the rather few in multifamily blocks. Also solar panels, which are considerably more cost-effective than solar cells, are more used, and have proved to be profitable in spite of the short summers in Sweden. A reduction of the energy needs by 15-25 % is expected and in some cases fulfilled. .(Vidén & Blomberg, in prep.)

Figure 1. Ca 380 m^2 of solar panels added on two buildings in a housing area, in the south of Sweden. The panels are erected transverse the almost flat roofs, facing south and the sun as efficiently as possible. The solar energy is stored in two water tanks of 15 cubic metres each, and the heat is used for heating as well as hot water for the totally 120 flats in six buildings. The out effect is calculated to be 150 000 kWh.

In most cases, improvements of the technical facilities are much more cost-effective than improvements of the envelopes. Spectacular measures like new, better insulated façades attract attention and may have other desirable effects, but as energy savers simple management procedures like adjustments of heating or ventilation systems should never be overlooked. Improvements of heating and ventilation systems, often combined with new, computer-based systems for supervision and operation control, help to reduce the need for heating energy substantially. In most cases such measures will also make the indoor climate better and facilitate the management of the systems. Systems for recovering heat from the ventilation air have proved to be cost-effective energy savers as well, and are often installed today.

Renovating and improving old electrical systems and eqiupment make the dwellings safer and more adjusted to modern living. In Sweden, the need for energy for electric lighting is high. Energy efficient equipment, including low-energy and/or time or presense governed lighting in common spaces, indoors and outdoors, usually reduce the energy consumption substantially. In general, measuring and charging of consumption of heat, hot and cold water, and to some extent even electricity, has been collective in multifamily blocks. In the last decade, equipment for individual measuring and charging has been installed in many post-war areas. The reduction of consumption usually compensate well enough for technical complications, rather big investments, and difficulties to reach agreements with the residents on a fair distribution of the costs. In addition, the measuring often make people more aware of environmental matters.

2.2 Improvements of the building envelopes

In spite of the very big energy needs for heating in Sweden, improvements of the housing envelopes are usually not cost-effective unless the materials and constructions used are in such a bad condition that they will need extensive maintenance or have to be replaced. (Vidén & Blomberg, in prep.) Today the specific energy use for new housing blocks should not exceed 110 kWh per m^2 floor space (A_{temp}) and year in climate zone south (in climate zone north 130 kWh). In housing blocks there are no specific maximum U-values for external walls, windows, etc, but average U-value for the envelope must not exceed 0,50 W/m^2K. Due to this lack of specific requirements it is not possible to point out specific needs for improved thermal insulation in existing buildings. In the national guidelines for rebuilding, however, it is stated that if extensive renovation of the envelope is needed, the possibilities to improve the thermal insulation shall be considered. As indicated above, the requirements for care for the original building characteristics may call for sensitive compromises.

Façades of housing blocks built 1946-75 which have not been thoroughly repaired before may need renovation, partly or totally. Their thermal insulation seldom fulfils the requirements of today. The most common façade material, brick, is normally in good condition and such outer walls will be kept in their original, yet aged shape. Almost as common is plaster on gas concrete or brick. Many plastered façades just need minor repairs, cleaning and maybe new paint. But due to the needs for better thermal insulation - enforced by insufficient sound insulation - a new finishing coat of plaster on additional thermal insulation of mineral wool or expanded plastic boards tends to be the standard solution. This solution has been in use since the late 1970s, also for façades covered by asbestos cement slabs or other thin panels, or prefabricated concrete façades. It has been used even for reshaping plaster façades on housing blocks which were insulated and covered by aluminium corrugated sheets in the 1980. The metal panels turned out to be far from sustainable. They were too easy to damage, the colours were not enough weather and light resistant, and the kind of mineral wool used for insulation was not performing well after a decade or two. Other solutions, where the additional insulation is covered by sandlime brick, which at a distance can look almost like plaster, are not as common. The higher costs, the need for a good foundation for the new, heavy brick wall, and the technical and appearance problems with the additional wall thickness which usually causes deep outer reveals and needs for enlarged roof overhang are some explanations. On the other hand these solid new façades will keep the maintenance costs low for many years.

Figure 2 + Figure 3. Before (left) and after (right) reshaping (2000-2002) of the original façade appearance of buildings of the 1950s. Not just the façades, but also the balconies got materials and colours corresponding to their original appearance.

Facing brick covering additional insulation is used mostly for ageing and leaking concrete panel façades, where wishes for a more prestigious appearance and reduced needs for maintenance influence the decisions as much as energy saving needs, and occasionally for existing brick façades in need of renovation.

Most roofs are moderately sloping gable roofs, which do not cause special problems and, in many cases, quite easily are given extra insulation. After 1960, many buildings were constructed with almost flat roofs, covered by roofing felt and drained by internal sewer pipes. For some of them careless performance, missing supervision, or too sparsely placed sewer pipes have caused problems. New roof constructions of more traditional types, and better insulated, have replaced many flat roofs. Also, new flats on top of the existing buildings may demand a total redesign. In some cases the new roofs are given a “traditional” design totally strange to the original, time-typical characteristics of the buildings. Sometimes the installation of solar panels have motivated the new forms. Many examples, though, demonstrate that solar panels can be well functioning and integrated to roof forms true to their time period. In renovation works harmful or decaying materials are often replaced by more sustainable ones, like rheinzink, or brick or concrete roof tiles.

Double-glazed windows with wooden (pine) frames, far from the recommended U-value of today, of maximum 1,3, are the common types in buildings from 1946-1975. A few percent of the buildings have original triple-glazed windows, usually with three separate panes. The oldest window frames are of good quality, but from circa 1960 rapidly grown, and rapidly decaying, wood was used. Insufficient thermal and sound insulation are frequent problems. Exchange of windows is often considered advantageous, even of windows with moderate deficiencies. Nevertheless, improvements of the original windows by additional glazing, and tightening, or tightening and filling the space between the panes by argon gas, will often be both cheaper and more cost-effective and resource-saving. Such solutions are also resource saving, and may be performed in ways which will not change the characteristics of the building.

The improvements are usually combined with measures to eliminate draught. Anyhow, a controlled air intake is needed to get a healthy indoor climate with a proper air change rate. Special air terminal devices may be installed in the upper frame of the old or new windows or behind the radiators, so that the air can be pre-warmed by heat from the radiators.

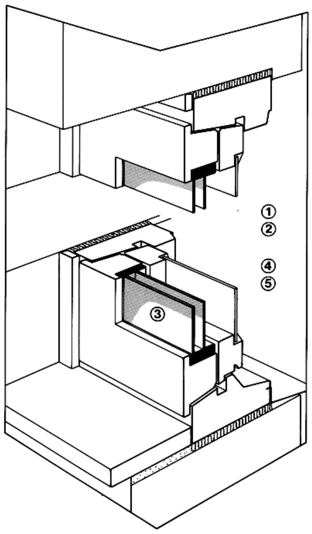

Figure 4 (left). The inner pane replaced by a sealed double-glaze panel. (Bjerking, 1987).

1-2 (preparations) Sealed double-glazed panels are delivered from the manufacturer. The inner casement is taken out, and the window-pane removed. The glazing rebate is enlarged. 3 The double-glazed panels are put in place and fastened by glazing beads of exact length; 4-5 Completing works: replacing the casement etc.

Figure 5 (right). A window renovated by a similar but more thorough method. The original external casement is replaced by an aluminium one with energy glass, and the single glass of the internal casement is replaced by a sealed double-glaze. The frames are covered outside by aluminium profiles. Around the window we can see an additional mineral wool insulation, ready to be plastered.

3 IMPROVING THE OUTDOOR ENVIRONMENT

Most renovation projects of this time period, include substantial development of the outdoor environment. Wear and tear often call for improvements, and especially in many of the housing areas of the 1960s and 1970s something has to be done to originally poor outdoor environments, substantially contributing to a common, negative image. (Hall 1999). Making the area more attractive by ambitious landscaping and a big variety of plants, trees and room-creating shrubbery and constructions has become a popular and quite effective concept. From an ecological point of view the wildlife in the areas is stimulated by the new biological diversity. Getting the residents engaged in their close environment, also by letting them have a direct influence, and even participate, in the everyday management, arranging allotment garden, etc does not just improve the physical environment, but also the social. The increased amount of "green" surfaces, the replacement of asphalt with more varied and lavish materials are not just nice to look at, they also help to take care of rainwater, which otherwise could cause problems in many areas built on flat, maybe swampy land.

Another, still more spectacular way of improving the outdoor environment is the local handling of rainwater. In quite a few areas rainwater has been led away together with wastewater, or just led to the ground, which has caused risks for flooding by heavy rains, or melting snow. The new solution is to build water systems with small and shallow streams or channels leading rainwater from the buildings, and from the ground nearby, to usually shallow ponds where particles and contamination will fall to the bottom. In dry periods, the water is pumped around to keep channels and ponds fresh. The water leaving the pond for nearby recipients is much cleaner than before, and the ponds, the running water, and the landscaping around them offer inviting places for wildlife and for residents. In addition, creating an outdoor environment which will be more useful and attract people around seems to be a good way to promote natural meetings and strengthen the social environment.

Figure 6. A natural brook, for decades hidden in an underground pipe, has been brought up to the surface again and is now part of the local rainwater system – a popular place for playing or just enjoying the natural design.

4. IMPROVING SOCIAL LIFE AND ACCESSIBILITY FOR DISABLED PERSONS

In quite a few post-war housing areas, especially among those built after 1960, segregation and alienation are long-lasting problems. Many measures directed towards resource saving and other "ecological" improvements will have indirect effects on social life – for instance the outdoor environmental measures described above, and the establishing of local recycling workshops, where under-employed residents can meet their neighbours in a meaningful work. In several areas, measures have been carried through more directly aimed at facilitating meetings and social contacts among the residents. New buildings with rooms for meetings, local information and exhibitions, leisure occupations, sports, laundries etc have been built, and often make the space between the original buildings more vivid. In other cases existing buildings have been rebuilt to give room for such occupations. Such measures are often combined with other actions, to make the renovation programme as a whole more effective. Reusing and rebuilding unlet spaces is one such combination, reusing parts of demolished or dismantled buildings another. When buildings are demolished, the crushed concrete is often used for creating hills and other enriching variations of the ground nearby the buildings. For instance, a big football ground was created on a small swamp close to the demolished buildings in an area with many youngsters.

Figure 7. A multi-functional common house for the housing area Norra Lövgärdet, Gothenburg, created by using the basement and the first floor of one of the central buildings which was dismantled. The concrete construction of the original building was used as far as possible. The new building is announcing its specific nature by partly glazed façades and a spectacular "green" roof.

The housing areas built 1946-1975 are dominated by flats with one or two bedrooms, which is not sufficient for most families. Bigger flats, and improvements of the accessibility for elderly people who have lived in the areas for decades, and want to stay on, are often a necessity to promote the social stability and sustainability. In Sweden today, lifts are demanded in all new buildings with more than two floors. In rebuilding of existing housing, this demand can be reduced, according to local conditions and municipal guidelines. Making 30 % of the flats accessible by rebuilding is often considered enough, even if the possibilities for elderly and disabled people to stay in their homes are given priority in municipal planning. Nevertheless, there is a substantial and resource demanding need for new lifts in renovation projects. Letting lifts occupy floor space of rented flats is seldom possible unless un-rented flats are frequent. Other solutions are more used, either using specially designed lifts in existing, rather narrow staircases or adding new staircases to the buildings to make room for the lifts.

Figure 8. This building got a lift inside the original staircase and new stairs in an addition to the original staircase. Well insulationg glass panels make the new staircase light and attractive. Enlarged balconies facilitate the use for disabled persons. The additions make the façades more vivid and expressive.

5 DISCUSSION AND CONCLUSIONS

Just a few of the rich variety of environmental measures for improving existing buildings have been mentioned above. They are chosen because they raise many basic questions about how to handle the different needs and demands in housing renovation. Upgrading decaying areas is a delicate task. A balance has to be found in every single case, to satisfy the technical and environmental needs, to improve the functionality for the residents, to be careful with the limited financial resources, to give the buildings and areas a more attractive appearance, and to pay reasonable respect to the original character, typical of its time.

Improvements of the building envelopes often get most of the attention when energy saving is discussed. Nevertheless it is quite clear that many less spectacular measures will be more, or equally, effective and cost-effecient. Chosing reversible measures is always a good idea when it comes to controversial desicions on architecture and design.

The costs are crucial for most renovation works. Unfortunately, it is seldom possible to predict the economic conditions well enough. The actual pressure on the building market, the special conditions of every single case, and the difficulties to define single costs in big renovation works make it hard to appoint some average building costs. Trying to find technical solutions which will give multiple advantages is a way of economizing with the limited resources.

What seems to be clear is that a broad application of good and proper solutions will add to the sustainability of existing housing, and simultaneously facilitate care for the existing building qualities. The rent potential may be increased by a thorough and sensitive renovation. In quite a few cases housing areas with many vacancies have turned to be much more attractive due to a number of carefully planned actions. One important factor has to be emphasized. Rebuilding of housing areas always concern the homes and the everyday life of people with different backgrounds, needs and wishes. The opinions and needs of the residents should always be considered and respected as far as possible. Environmental measures, which often demand collaboration with the residents, will probably work better if they are based on open discussions and mutual respect.

REFERENCES

Bjerking, S-E (1987): *Skador på hus, vad gör man? Ytterväggar och fönster.* (Damages on buildings, what to do? External walls and windows) T13:1987, Byggforskningsrådet, Stockholm.

Botta, M (2005) *Towards sustainable renovation. Three research projects.* Doctoral thesis, KTH, Arkitektur, 2005.

Boverket (2003): *Flerbostadshusens förnyelse. Behov och förutsättningar 2002/03*. (Renewal of multi-family housing. Needs and conditions 2002/03). Boverket, Karlskrona.(Authors Vidén.S & Blomberg.I)

Hall, Thomas (ed) (1999): *Rekordåren, en epok I svenskt bostadsbyggande (The record years, an epoch in Swedish housing construction)*, Boverket.

Vidén, S & Botta, M (2006): *Bostadsförnyelse och miljöåtgärder med stöd av Lokala Investerings-Program...* (Housing renovation and environmental measures supported by Local Investment Programmes. Sustainable development in housing areas of the 1950s, -60s, and -70s). Not printed.

Vidén, S & Blomberg, I (2007): *Teknik för hållbarhet* (Techniques for sustainability). To be completed.

Sustainable technologies in the refurbishment of existing building envelopes in Italy

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ABSTRACT: With the new European Energy efficiency regulation building are forced to respect restricted standards for energy saving. In the last ten years building envelope has become more important in the overall energy balance, as a dynamic surface able to optimize its performance in relation to different climatic inputs (passive or active). In this sense it will be desirable to manage the necessaries refurbishment actions in the direction of the passive solar gaining, natural cooling and other relevant sustainable technologies for building envelopes which are presented in this paper.

1 INTRODUCTION

By considering that more than the third part of the Co_2 polluting gas responsible for the greenhouse effect is caused by building activities, one easily realizes the relevant role of architecture as regards the theme of the global sustainability. Nowadays, improving the quality of the existing real estate is a widespread building activity that requires various and important interventions such as structural, technical, architectural, functional and energetic upgrading. In particular, poor materials and single paned deal window frames were used, without paying any attention to energy conservation especially owing to the lack of technical standards and building regulations.

The most important problems are connected with the façade decay, the lack of acoustic and thermal insulation and the presence of thermal bridges. In the last decade, an awaking policy focused on the protection of the environment is in progression in Europe like as all over the world, with a special attention to energy waste in the building sector. A basic improvement in this field is the EPBD 2002/91/CE that, following the Kyoto Protocol, promotes the energy efficiency of buildings. As from January 2006 this set of rules has been acknowledged in Italy by enacting the Decree 192/2005, and his following upgrading Decree 311/2006, that states new standards for the energetic performance of buildings, considering also the existing stock. The experiences gained since now in other Countries seem to test wide chances of interventions on the post war building stock, even if the building techniques and the state of decay are various, by using techniques and materials free from cultural and historical meanings typical of cultural heritage. According to these experiences it’s possible, therefore, not only to introduce basic functional improvements but even proper architectural lifting. In the last decade the urban building envelope has come forth gradually into being a dynamic and active bounding surface. It means that the envelope is automatically able to gear its performance to the changes of the environmental conditions, as it integrates active functional devices.

Consequently, the refurbishment actions have especially to be made by considering the chance of the natural resources, following the sustainable architecture statements that outline the exploitation of alternative sources of energy. A sustainable upgrade of inadequate buildings should mainly provide active or passive energy from renewable sources in order to achieve the highest indoor comfort by restricting the use of air conditioning units and artificial lights. About the above mentioned issues, the most efficient technical solutions are based on fundamental principles of the sustainable architecture such as: heat gaining by collecting and storing solar energy in winter, use of passive cooling and natural ventilation in summer, maximum natural lighting, reduction of heat transmission through the walls, using systems with low environmental impact such as dry technologies. The strategies of intervention that can be usd in a sustainable refurbishment may be briefly summarized as follows:

- Improving of technical and acoustic performance (External thermal insulating systems, Ventilate façades, Double skin glass façades)
- Solar shading (lamellas or panels, replacing of windows with Low –E high-performing glass)
- Passive solar energy systems (Transparent Insulation materials, Solar glazing balconies)
- Active solar energy systems (Solar collectors, Photovoltaic modules)

2 STRATEGIES OF INTERVENTIONS

A first evaluation of the above mentioned four basic strategies of intervention is based on the difficulty of realization and, consequently, the cost. The classification in the following tables can be useful to compare the efficiency of the different way of refurbishment, mainly related to the cost levels and the employment flexibility. Technical solutions that consist in the overlapping of a new façade, without modifying the existing façade, are more economical also because, in the most cases, the users can stay in the building during the works. Costs are higher when the refurbishment action requires the replacement of the existing envelope, where generally a multitude of variables has to be considered.

Table 1: Strategies of intervention in relation to the existing envelope

	Type of intervention	
Techniques	Overlapping to the existing envelope	Substitution of the envelope
ETICS	X	
Ventilated façades	X	
Double skin glass façades	X	X
Solar shadings	X	
Low E glass		X
TIMS	X	
Glazing balconies	X	
Photovoltaic modules	X	X

Table 2: Strategies of intervention in relation to the typology of building

	Type of intervention	
Techniques	Residential	Office/tertiary
ETICS	X	
Ventilated façades	X	X
Double skin glass façades		X
Solar shadings	X	X
Low E glass		X
TIMS	X	X
Glazing balconies	X	
Photovoltaic modules	X	X

In this datasheet, the potentialities of ventilated façades, double skin glass façades and solar shadings as refurbishing solutions, mainly for post war buildings, will be assessed.

2.1 *Ventilated façades*

The use of a ventilated façade in the refurbishment and upgrading of existing buildings is indicated for a multitude of cases, for example:

- Lack of thermal and acoustic performances;

- Façades with detachment of cladding, attack by weather or moulds;
- Façades which presence of damages in the cladding, or cracks in correspondence of the concrete frame and the infill walls;
- Walls with strong construction dimensional tolerances, compensated by plaster thicknesses, which is very variable depending on zones. In these cases the integration of the plaster is technically problematic due to the big thick of the layer and it's quite impossible the gluing of other claddings;
- Walls with high hygrometric dilatation coefficients, usually interested by diffused cracks;
- Façades which are not more coherent to the user changes (typical of commercial, offices and industrial buildings).

The system is composed of external cladding, dry mounted, fixed to the existing wall by means of stainless steel devices that also supports insulating panels. Between the cladding and the panels an air cavity, 5-10 cm of thickness, allows natural air circulation that is helpful to reduce heat gains during the summer, to increase thermal insulation and to reduce heat losses and condensation in winter.

The use of a ventilated façade is becoming increasingly common in the refurbishment and upgrading of any building envelope. This technical solution, overlapped on the existing façade, can solve a multitude of technical problems by improving thermal and acoustic insulation and protecting from moisture and atmospheric agents. Furthermore, the recent development of high-performance claddings offers a wide range of opportunities for upgrading the image of the building to meet new architectural requirements. The use of a ventilated façade is not limited to any type of building. The multitude of claddings available on the market allows to find a peculiar solution for each problem, and the design optimization for the different building envelopes. The fundamental factors to evaluate for the addiction of a ventilated façade are:

- The planarity defects and other issues related to the condition of the existing wall, which can influence the modality of anchorage;
- The mechanical resistance of the support, which can be heterogeneous an insufficient in some parts;
- The adequate protection of the insulation layer, which has to be permeable to the vapour coming from the inside but protected from external water;
- The adequate protection of the air cavity to avoid the entrance of insects and other animals;
- The realization of the façade joints, to avoid mechanical tensions in and on the cladding elements.

A specific design, particularly related to the peculiarity of the situation can be profitable in the improvement the technical and architectural quality of the building with reasonable costs and environmental positive effects.

Figure 1-2: Ventilated façade in the refurbishment of a residential building in Modena (before-after)

2.2 *Double layer glass façades*

A particular case of ventilated façade is represented by the so – called "double layer glass façade". The most useful field of application of this solution is the tertiary sector (mainly offices and productive buildings) in which is easier to find financers who believe in the power of a new high-tech image of the building. Recent studies are investigating the possibility of application of this technology even for residential buildings. A typical double glass envelope system comprises a layer of single glass and a layer of double-glazing, separated by an air space. An operable shading device or heat absorbing glass can be installed in the air space to minimize the solar heat gain. In addition to the energy savings, the double envelope system has other potential benefits such as acoustic control, water penetration resistance, and improved office atmosphere because of the view and utilization of daylight. The double envelope system also offers a choice for renovation of existing building facades to transform into more energy efficiency buildings.

Double glass façades in the refurbishment are generally hybrid systems, formed by the existent wall and a new glass envelope. The external envelope is a glass façade: this helps in the solar gaining during winter season, in the heating of the air cavity and in the consequent improvement of the thermal capacity of the whole system. The use of high – performing glasses is fundamental to obtain solar reflection and to avoid overheating. If the refurbishment is oriented to the complete substitution of the existing envelope, the internal wall is either a glass façade, forming the conventional double-layer skin. In the most cases it's more convenient to leave the existing wall, replacing the windows and adding insulating panels on the structure and on the parapets.

In winter, during the warmest hours, the heating of the air cavity is the fundamental factor that helps in the reduction of thermal losses and of air permeability through the wall. During the night, the air vents are closed to avoid the entrance of cold air. In summer, thanks to the solar shadings, good levels of internal comfort can be obtained. During the day the cavity is closed, to avoid the entrance of warm air, while during the night the natural cooling can refresh the walls and the rooms. The cavity in double glass façades is either naturally or mechanically ventilated. Natural ventilation can provide an environmental friendly atmosphere and reduce the requirement for mechanical ventilation. On the other hand, natural ventilation is not without risk. It may create a door-opening problem due to pressurization. Besides, if the air path is not appropriately designed, the solar heat gain within the façade cavity will not be removed efficiently and will increase the cavity temperature. In urban environments, natural ventilation systems may also experience significant problems of noise transmission and pollution and may result in uncomfortable indoor environments in extreme weather conditions.

Therefore, a natural ventilation system is more suitable in suburban areas with temperate weather where the airflow in the cavity will be close to the indoor air condition.

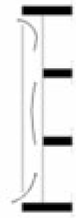
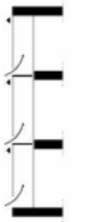
The thermal performance of double façade systems depends on many factors, such as:

- The composition and performance of the layers (glass/glass or glass/wall and the type of glass);
- The height of the air cavity (which can be continuous or divided in horizontal or floor-height cells, in this case the ventilation is related to each cell);
- The thickness of the air cavity (which can range between 20 cm to 90 if contains maintenance routes);
- The type of ventilation in the cavity (natural or forced) that is strictly related to the height of the façade and to the climatic conditions;
- The relationships between air cavity and HVAC systems (possibility to utilize warmed air from the cavity and expel internal air. This is rare in the refurbishment).

Because the interactions among these variables are complex, current computer simulations approaches may be inaccurate. Therefore the energy savings and cost/benefit of these systems are not well established.

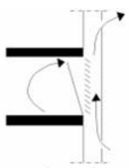
The relationships between typologies of façade, type of ventilation and applicability in the refurbishment are synthesized in the following tables.

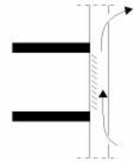
Table 2: Main typologies of a double-layer glass façade and applicability in the refurbishment

Typology of façade	Scheme	Description	Air cavity (cm)	Applicability	Cost
Full height		The external façade is independent from the internal, the air cavity is continuous	40/90	X	X
Pipes		The external façade is fixed to the internal by means of a common frame or punctual anchorages. The cavity is vertically sectioned.	20/50	-	-
Cells		The façade is formed by the aggregation of modular cells, independent each other. Each cell has his inlet airs.	20/30	-	0

X= High
- = Medium
0 =Low

Table 3: Main types of ventilation in a double-layer glass façade and applicability in the refurbishment

Typology of façade	Scheme	Description	Applicability	Cost
Natural ventilated façade		*The air in the cavity flows naturally (chimney effect).* *Internal layer=insulating and performing layer* *External layer= single glass*		
Relationships between inside/outside		Internal windows can be opened. This allows the natural ventilation of the rooms, even it's necessary to carefully evaluate the right period of opening (winter day-summer night), otherwise the positive effect of the natural air are neutralized.	X	-

No Relationship between in-side/outside		Internal windows can not be opened. This helps in the air cavity control, but decreases the user requirements (necessity of fresh air).	X	0
Forced ventilated façade		*The air in the cavity flows by means of me-chanical devices. Inter-nal façade is closed. In some cases warm air in winter and cold air in summer are utilized by HVAC systems.* *External layer= insulat-ing and performing* *Internal layer=single glass*	0	X

X = High
- = Medium
0 =Low

The most useful typology in the refurbishment is the full height façade: generally the juxtaposition of a new glass layer doesn’t requests big modifies to the whole system. In these cases original windows are substituted with double-glass windows and an insulating coating is applied on the opaque parts. The natural ventilation of the cavity doesn’t involves plants modifies. The careful design of the air cavity (thickness, position and dimensions of air vents) is fundamental as the phenomenon of natural draught works properly. The use of a pipes or cells façade is more convenient where the height of the building is such that natural flow is impossible.

Since the Italian regulation imposes the natural ventilation of the rooms in residential buildings, windows can not open only on the air cavity, as it happens in tertiary buildings. By the way, there are two main solutions which can be evaluated:

- The realization of a partial glass façade, cells or pipes formed, only in correspondence of the opaque walls;
- The realization of a moveable external glass envelope.

The realization of the intervention has to be carefully planned and designed, to evaluate which will be the more coherent and resolute solution. This could be done with the support of the producers, which put at designer’s disposal their technical competences for the realization of the façades, supporting more than the diffusion of specific programmes, the executive designing and the performances verify.

Figure 3-4: Double skin glass façade in the refurbishment of an office building in Milan (before-after)

Fields of application of a double layer glass façade are, at the moment, mainly related on offices buildings. Many example of refurbishment can show that, with this high-energy performance technical solution, high levels of thermal comfort and energy saving are obtained (ranging from 20 to 40% of reduction of the overall building consumption). The high investment costs for a refurbishment are, in the long term, remunerated by the reduction in HVAC use. The challenge is represented by the application on residential buildings.

2.3 *Solar shadings*

A solar shading can be used to control the diffusion of the light through a glazing surface and to reduce the heat gains through an opaque wall. Solar shading systems allows the incidence of the rays of sun during the winter which consists a benefit for the overall thermal balance of the building. On the other hand, during the summer, the overheating of the rooms due to the incidence of the sun on the windows has to be avoided. The use of solar shadings is becoming increasingly common in the refurbishment of building envelopes. The recent development of high-performing envelopes and the growing importance assumed by glass, has influenced the development of techniques and materials oriented towards the control of the solar factor. The choice of the solar shading depends on the type of surface: adjustable solar shadings are more suitable for glass windows while fixed elements can be used for opaque surfaces. A lot of typologies are available, which can be classified according to: shape, material, movement. A first classification can be done in relation to the envelope in: external solar shadings, internal solar shadings and solar shadings between two glass panes in the windows or double layer glass façades. In the field of the external solar shadings, windows elements (e.g. venetian blinds) and solar shadings for façade (e.g. lamellas or panels) are included. Comparing to an internal solar shading, the overlapping of an external solar shading is more effective for the overall energy balance in terms of energy efficiency, for the following reasons:

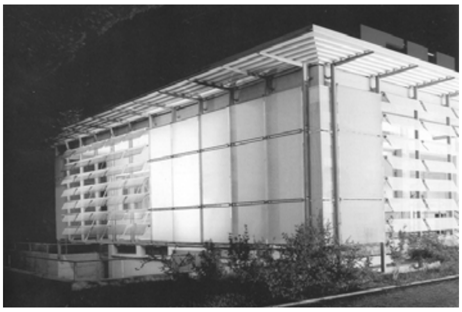
- The interception of the rays of sunlight before they heat the surface and the optimal control of the diffusion of light and heat;
- The reflection of a part of solar radiation and its dissipation, which depends on the material and on the color of the surface;
- The reduction of thermal losses, in the case of adjustable elements, which can be closed during the night.

For these reasons the efficacy of an external solar shading is about the 30% above to internal shadings. In south facades, where the sun is high on the horizon, horizontal shadings are more suitable. Particularly indicated in summer season, an horizontal shading can hamper the rays of light in winter, therefore is more suitable the use of adjustable or mobile systems.

Vertical solar shadings are more adapt for East and West oriented façades, where the sun is low.

Comparing to a fixed system, the use of an adjustable system allows to change the position of the elements in relation to the direction and the intensity of the rays of sun. Therefore, with this solution it's possible to control each element during the day and also during the different seasons, to achieve the optimal daylight factor and to avoid undesired solar gains.

Figure 5-6: Overlapping of lamellas and panels solar shadings in the refurbishment of an office building in Lecce



3 CONCLUSIONS

In the last two decades, good examples of new sustainable architectures provided realistic inspiration and practical experience of how architects, and their clients, have achieved sustainability.

They demonstrated a wide variety of approaches to design and technical issues – including passive solar design, good daylighting, natural ventilation, night cooling, combined heat and power, photovoltaics, grey-water recycling, and the integration of landscaping. The today's challenge is focused on the improvement of the existing buildings, in order to reduce the overall energy balance which is mainly related to the envelope. Renovating façades often coincides with changes in the architectural appearance of a building, and large investments to improve the quality of the building envelope are justified if the building block as a whole can meet future requirements.

REFERENCES

- AA.VV., 1996, *Energy and climate in the urban built environment*, James & James, New York
- Acocella A., 2000. *Involucri in Cotto – Sistemi innovativi per il rivestimento in architettura*, Sannini Impruneta, Firenze
- Bazzocchi F. (edited by), 2003. *Facciate Ventilate. Architettura Prestazioni e Tecnologia*, Alinea, Firenze.
- Brunoro S., 2006, *Efficienza Energetica delle facciate. Standard, requisiti, esempi per l'adeguamento e la riqualificazione architettonica*, Maggioli, Rimini.
- Compagno A., 1999, *Intelligent glass facades*, Birkhauser, Berlin
- Daniels K.,1997, *The Technology of Ecological Building*, Birkhauser, Berlin
- Lucchini A., 2000. *Le Pareti Ventilate – metodologia di progettazione e messa in opera di materiali e componenti*, Il Sole 24 Ore, Milano.
- Schittich C.,1999, *Building Skins. Concepts, layers, materials*, Birkhauser, Berlin
- Sala M. (edited by), 2001, *Recupero edilizio e bioclimatica*, Esselibri, Napoli,

Sustainable recovery approach to the existing housing stock in Italy

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ABSTRACT: The current Italian situation in the pre-existing building sector and the forecasts for its future lead to reflections on aspects of the wider European picture that might help us better understand future patterns in our national context. The theme of adapting residential buildings, which have been built using non-traditional methods, demands in particular both an overall vision of the strategies to use to carry out intelligent interventions, and a methodology that leads to the achievement of aims that are coherent with the concepts of sustainability.

1 INTRODUCTION

The priority in the next few years, or the next few decades, is confirmed by the way the construction market is shaping up: a more rational use of urban resources in the pre-existing residential sector.

Of particular interest from this point of view is the recovery of materials used in building that were made with industrial and prefabricated technologies that, despite their comparative newness, demonstrate an advanced degree of deterioration, and which require not only serious remedial work at the level of the buildings themselves, but also the cleaning up of whole urban areas, along with the development of infrastructures and related services.

This is recognised as a prevailing aspect in different European contexts, where it is possible to carry out a meaningful comparison with the situation in Italy with regard to the conditions, spread and reasoning that led in the 30-year post-war period, with slight variations on this timescale, to the creation of the majority of the residential property that exists today. The indications, both theoretical and practical, for interventions stem above all from a number of phenomena which appeared over the last few decades and which can be summed up as follows:

- the movement from a culture of expansion to a culture of redevelopment, especially in Italy, caused by a lack of demographic pressure and by the substantial dimensions of the building stock which benefited from maintenance work: in synthesis, the normal procedures for planning and operating should be in line with the notion that the spaces that, in the future, are going to house a large part of residential property and workspaces already exist;
- the appearance of serious signs of deterioration in the building stock from only a few decades ago, which led to the term "architecture of deterioration" being coined, has already become an emergency which imposes the need to carry out enormous building redevelopment and salvage operations, which pose technical, planning and methodological problems which are quite different from those that had to be confronted when dealing with historic town centres or buildings of historical importance;
- the substantial distance which, in the past, has separated the planner from the resident, along with the misunderstanding of the freedom of expression and to experiment of the former, and

the results of this on the latter, the inhabitants, who didn't have the same freedoms and whose background, cultural roots and needs were ignored;
- the possibility of analysing the building that's to be redeveloped in a profound way that's not destructive, and so to intervene on the same with appropriate means, also employing highly innovative planning techniques, which are thus able to find their points of reference not so much in the expansion of a building or in replacing old with new, as in a more considered re-reading of what's already there, in the ongoing work of the functional adaptation of a physical reality.

2 SUSTAINABLE APPROACH

That which might have represented a critical reflection on the means of constructing quarters and buildings in the past instead comes to constitute the starting point for focusing on the problem of sustainable redevelopment.

In reality, as borne out by the valid results of a number of projects both at a national and European level, refurbishment interventions have to be the consequence of synergy and collaboration between various sectors, sciences and fields of knowledge: sociology, economy, urban planning, engineering and law have to be managed and made to work with each other. All the same, the increasing degradation of these buildings demands – both for how widespread it is and for the seriously obsolescent conditions in which they find themselves – a rapid reaction followed by action, and the identification of a tried and tested strategy able to limit as far as possible an eventual loss of control that would render future events unmanageable.

Contemporary renovation experiences in Italy underline both the problems encountered in other countries as well as the shared need for a sustainable approach to what already exists. The principal difficulties that will be encountered can doubtless be blamed on the deterioration of the buildings, but, there are also problems in the management and financing of interventions.

A number of organisations in Italy, such as ATER (Azienda Territoriale per l'Edilizia Residenziale – Regional Residential Buildings Company) of Rome, are only now launching new strategies for carrying out redevelopment programmes, and turning to Project Financing – as allowed for in Legislative Decree 163/2006 (Code for public contracts relating to works, services and supplies in carrying out EU directives 2004/17/CE e 2004/18/CE) – making the most of the potential benefits that would come from the running of the production of renewable energy sources, especially solar power.

Management represents, therefore, faced with projects and existing plans for recovery, one of the essential conditions for the activation of a process of renewal of building stock which has been long-awaited and hoped for in our country, but which up to now has not taken off.

If, on the one hand, many experiences favour turning to the external upgrading principally of building envelopes using add-on or substitution strategies, and with modifying internal living spaces, the lack of a consolidated redevelopment culture reveals itself. Interventions, mostly carried out on time, are still lacking at the level of correct planning both nationally and locally.

This incapacity is doubtless exacerbated by the greater percentage of owned rather than rented property, which is largely down to previous policies for running the public housing stock, which were subsequently revealed to be mistaken and which, in some way, limit the possibility of planning new interventions, even important ones, to demolish or redevelop for a different use, as instead happens in other European situations. A consolidated culture which aims more at conservation rather than renewal such as we find in Italy still lacks the inclination and experience to be able to confront in a decisive and knowledgeable manner an overall modification in residential buildings.

2.1 *Sustainability or energy efficiency*

Before looking further at the theme of sustainability in recovery interventions, it's useful to clarify a number of differences inherent in the concepts, which are often used incorrectly, of sustainability and energy efficiency, and which might create misunderstandings even among those who work in the field.

In the original concept of sustainable development, from which was born in 1992 Agenda 21, the environment was placed at one of the corners of an ideal square, whose other corners were occupied by the economy, social background and culture. Such a concept, expanding its areas of concern, led to an interchange ability among applied research sectors, underlining the need for an ever more integrated and complex approach to the project. Thus the notion of the environment as oppositional force and a brake on economic and social development was overcome, but it placed itself as an essential element which had to be the starting point for long-term progress that won't compromise the survival of the planet and the life of future generations.

This definition of sustainability constitutes the starting point, the reference, the framework and the expression of the principles within which the international community, nations and local authorities are moving, taking it on as a fundamental aspect in the process of governance and in the decision-making processes for the development of a given area.

Energy efficiency, on the other hand, is a specific aspect of sustainability and therefore has to be considered as a prerogative for interventions but not as the single all-inclusive element to be aimed for. With the Legislative Decree 192/2005, the EC directive 2002/91/CE was introduced into Italy, which controls the production of energy in buildings. The provision establishes, among other things, the criteria, conditions and means to improve energy performances in buildings with the aim of favouring development, increased value and integration of renewable resources and energy diversification.

European directives and national laws are intended therefore to increase energy efficiency and improve its availability, defining measures aimed at promoting and developing, including at an environmental level, the generation of high levels of heat and energy, based on the demand for useful heat and on the saving of primary energy, with particular reference to national weather conditions. Apart from the new element foreseen by the Italian Law no. 296 of December 27th 2006 (Budget 2007), on February 2nd 2007 the Legislative Decree 311/2006 came into force which alter the Legislative Decree 192/2005 and extends, starting from July 1st 2007, the obligation for energy certification to existing buildings of over 1,000 sq.m and further increasing a number of regulatory values.

It's in this sense that the adopting of European Directives at national level with the Circular of 31/05/2007 no. 36 which fixes at 55% the tax relief for energy redevelopment interventions on existing buildings (from which stems the Decree of February 19th 2007 which modifies article 1, subsection 344, of the Law of December 27th 2006, no. 296), aimed at obtaining an index of energy use in the winter at least 20% lower than previous values. Particular attention was again paid to interventions on the envelopes of existing buildings with regard to opaque horizontal and vertical structures, frames, delimiting heated volume, towards the exterior and towards unheated spaces, defined in respect of new thermal transmission values U, expressed in $W/m^2 K$, relative to the six climatic zones Italy is subdivided into.

The buildings involved have to be pre-existing, and the incentive is aimed at strengthening those procedures which seek to preserve the building heritage, raising the tax relief and reducing the number of years it has to be divided over. The European advice of spring (OR. EN 7224/07 of March 8th 2007) gave a further push to the European policy against climate change, underlining the close interdependence between energy policy and the leading role of the European Union in international climate protection, in view as well of the system that will replace the Kyoto Protocol in 2012. In this sense, in both the European advice and the application of the recent decree granting incentives for photovoltaic activities, the aim of growth in renewable energies is made explicit and requires 20% of total EU energy consumption to be renewable by the year 2020.

With the launch of this programme, a number of provincial and local organisations, including Rome City Council, have already set in motion significant works in the field of energy redevelopment in existing buildings and in new builds, introducing variations and integrations to the Provincial and Council Building Regulations with laws for saving energy, the use of renewable energy sources and the saving and recovery of water resources.

The picture is made even more complex by the specific intervention programmes for energy redevelopment which control and define the granting of funding on the part of the European Community. Among these, Jessica (Joint European Support for Sustainable Investment in City Areas) constitutes the recent European support for sustainable investments in urban areas. This programme foresees the gathering together of grants aimed at programmes of urban redevelopment and development (including the social housing sector), with loans and financing that stem from a partnership between the Commission, BEI and the European Council Development Bank.

Against this background, recovery activities underline the relevance of the redevelopment of external closures (envelope) even with the knowledge that, despite the value of its planning characteristics – as much in respect of requirements linked to image and communication of the buildings as of those connected with environmental comfort and energy consumption – the specific intervention on the envelope has to be the result of synergies and actions of greater depth than those described above.

There's no doubt in fact that it's not sufficient to redevelop merely the envelope without reorganising the internal spaces on the basis of new needs, without reordering or projecting the viability, the running and the use of the external spaces and the balance of the whole set-up. The recovery of residential buildings cannot however remain a problem whose solution is to be found only at a planning-technological level, but it has to start to bear in mind social dynamics, changes of use and variables in scale (from the surrounding area to the building), which has implications for the architectural and construction impact of buildings, for environmental resources (space, materials and energy), for the image and on the social structure of an area.

The testing ground is therefore an intervention on an existing building capable of combining both the typological-distributive aspects as well as those of building technology: in many Italian cities, but especially abroad, experiments have been carried out which, with varying results, have involved public and private bodies working together with a common aim. In the context of building redevelopment, what is emerging in the need to identify means and operational instruments aimed at the tightening up of the physical, technical and user efficiency of the building organism and/or some of its parts, and the integration of any missing functions. Results so far, although often very interesting, cannot be reliably reproduced in different contexts.

The search for coherence between the need for the recovery of buildings and the sustainability of interventions on buildings highlights the theme of correct technical information and of methods aimed at choosing the most suitable strategies and instruments for the task in hand.

Recovery activities for existing building stock necessarily move from the starting conditions of the object to be worked on and from a structural organisation of the architectural organism according to the subdivision of subsystems, technical elements and materials.

What's necessary, therefore, is an approach to the project based on a needs-planning approach that permits the analysis of the level of deterioration and obsolescence of the existing building and which justifies and guides what to do next: a complete diagnosis that permits the identification of residual performances, of pre-existing obligations and of the picture of the new needs, so as to clarify the requirements, priorities and objectives of the project.

The principle prerogative for a coherent carrying out of redevelopment interventions is therefore the use of a methodological-operational set of instruments by which the activities to be carried out can be aimed, encouraged and controlled, and, in particular, a:

- definition of the technological units and technical elements which, inside the technological system of residential buildings, constitute the envelope of the building system under analysis;
- definition of qualitative parameters aimed at guiding the recovery project for residential buildings, and the formulation of a means of control and evaluation of the quality of the pre-existing and of the final quality achieved through the project on the building;
- initial evaluation of a picture of needs which will be used to define the priorities and aims of the project;
- definition, establishing and valuation of the needs related to the external envelope where the interventions will be carried out;

- identification and organisation of the technologies available on the market that are best suited to the redevelopment of the external envelope.

What this means, specifically, is the elaboration for each intervention on a pre-existing building of a “knowledge project”, a system of information closely connected to the context under analysis and capable of confronting it in all its complexity: in this way a planned project is imposed, one that is articulate, open, and multidisciplinary, with the aim of being able to determine its own reorganisation as further information is acquired.

In the light of recent experiences in redevelopment, the success and difficulty of an intervention consist in the capacity of the project to link with the qualities which the extant building already offers and which, on a case by case basis, will be preserved, improved or integrated.

Given the relevance and complexity of the concept of quality – an indispensable given for any project on a pre-existing building – it’s opportune to investigate the attributes that distinguish it within of the entire useful life of a building, both in relation to the process that characterises redevelopment, as well as the final verification of the end result of the recovery and its relation to the original stated aims. The principal of responsibility, in light of the transformations that are of interest to contemporary society, contributes to amplify the content and forms of the planning reflection and encourages the reconsideration of local situations which lessen the dependence on standardised technical solutions and housing models, but which continue to look for coherent solutions in technological potentialities and the living cultures of the areas.

A complete approach to the theme of redevelopment involves a complex approach to the aspects which contribute to the satisfaction of expressed or unexpressed needs; the capacity of planners will therefore be that of identifying the correct solution that’s able to resolve the instances linked to the themes of quality that are raised by all those who come to be involved in the recovery process. Alongside the identification of elements on which to intervene we therefore have to place the need to make explicit and fully satisfy the qualitative aspects that have to be observed. The concept of quality is intended in a very wide sense and includes all those aspects that make a building work suitable for the needs and activities of those who use it. This complexity leads to the search for a multi-criteria method which has the aim of confronting together factors of a different, multidimensional and not always measurable nature. It follows that the requirements be classified according to a complex scheme, in relation to and in order of quality, attributes or properties, by means of the performances offered, and able to satisfy any requirements that emerge.

The qualitative parameters, although they may come to assume variable levels of importance and weight, represent the fundamental decision-making input of the project which can be translated into different solutions for different environmental realities. If all this is evident in a new build, the problem is even more present in the process of recovery, where the inter-relations between pre-existing technologies and new requirements underlie different intervention strategies that are capable of leading to integrated and durable building projects. The aim of the initial diagnosis is therefore to direct the decision-making process and to provide elements of information aimed at motivating and guiding the choices to be made. The correct predisposition of the diagnosis furthermore allows the reading of recurring interventions, of a spontaneous nature, produced by the users over time, which represent both the highlighting of a number of problems that are linked to obsolescence and also a powerful push which shouldn’t be overlooked in the planning phase because it demonstrates the true “Habitus Habitandi”.

In this sense *habitus* represents, on the one hand, the clear frame of reference to identify and, on the other, the solid scientific basis which, taking into account all the environmental, technical, social, economic, management, legal, historical and cultural related aspects, renders itself necessary to look more closely at the state and conditions of the technological, physical and economic obsolescence of buildings. The finely balanced debate on the need, on the one hand, to evaluate and, on the other, to translate the notion of quality into terms that are never less than objective and legitimate, can only be achieved by a systematic approach and a continuous and gradual movement towards actions that are particular to each transformation, seeking out, nonetheless, the minimum common denominator in the process of the experiences.

2.2 *Instruments for a project of sustainable redevelopment*

The definition and evaluation of recovery interventions to be carried out are two extremely delicate activities because a construction and the environment in which it is to be found form a complex system where all the subsystems influence the total efficiency systems and where the interdependence between subsystems has an important role.

A great deal of research and study has been carried out in recent years in an attempt to focus and control redevelopment interventions in order to guarantee acceptable levels of quality that are in line with the various disciplinary requirements.

The first recovery programmes based on a sustainable approach of this type were born in France in 1972 and promoted by HVS (Habitat et Vie Social) availing themselves of a decision-making system (DSS) and network systems to enable global functioning. The *neural network* is a further method of evaluation which, following the function of the human brain, is able to receive data and, at the same time, the previously available and recognised connections between the elements.

It was on this basis that in Europe the first methodologies for evaluating redevelopment interventions were born – like that used for assigning the NPR (National Prjis Renovatie) – which makes use of a methodology of multi-parametric analysis. Defining recovery as an integrated system, it's very evident that there are many neural routes that can be identified and analysed, but what still hasn't been completely attained today is the global recognition of the elements to observe and of the network of connections between them.

The results that were provided in the WG2 research – in the recently finished Action COST C16 - reinforced the judgment on the individuality of every redevelopment project while pointing out that there are recognisable strategies of intervention that can be adopted. In the research, the problems related to needs were analysed, taking further the multi-parametric analysis that was applied to the themes of redevelopment in the different countries taking part. The research, furthermore, confirmed the difficulty of identifying a single planning solution that would, on the one hand, be capable of answering all the observed indicators, and, on the other, reach a degree of quality that would prove satisfactory to all the countries involved.

The theme of control and leading a project is further supported by a number of instruments of particular interest that derive from the latest research at a European and national level. Among these we find EPIQR (Energy Performance Indoor Environment Quality Retrofit) and TOBUS (Decision-making Tool for selecting office Building Upgrading Solution) – which are two research projects of the JOULE programme of the European Commission which have provided the basis for a new generation of instruments to assist in sustainable redevelopment interventions. The principal aim of this research was the development of an instrument – whose EPIQR software is the most evident example – aimed at evaluating retrofitting strategies, costs, and the activities aimed at satisfying those needs whether from the point of view of optimising energy consumption, the use of renewable (solar) energy and the improvement of the internal environment (Indoor Environment Quality). This instrument also permits the analysis of the physical deterioration of the building, the cost of the recovery intervention, the technical feasibility, the energy costs, the indoor environment quality and the predicted development of the deterioration, placing the emphasis principally on the energy question which is set at the centre of the decision-making process right from the start of the project, and therefore before the definition of the initial investment budget.

Still in a European context we recall the HQE^2R Project financed by the European Union within its Energy, Environment and Sustainable Development Programme of the V Programme R&D and coordinated by the CSTB. This project involved 7 European countries – including Italy – with the objective of defining a method to direct recovery projects towards solutions that aim towards an improvement in the quality of urban life: in other words, redeveloping the city from an environmentally sustainable point of view. HQE^2R, which was launched in 2001, has supplied, to public administrators and workers in the sector, suitable instruments for evaluating the possibilities of recovering the built environment, starting in terms of sustainability of existing buildings, which have to be well-integrated into their area and which will contribute in time to forming its identity. The peculiarity of the approach suggested by HQE²R lies in the four principle phases that make it up:

1.Decisions: preliminary identification of the problems and initial strategic decisions;
2.Analysis: gathering data (inventory) and diagnosis of possibility for sustainable development;
3.Study of the action plan: creation and evaluation of alternative scenarios;
4.Action and evaluation: implementation, monitoring and evaluation of the action plan for the sustainable recovery of the area.

The elements of sustainability which have integrated the methodology of evaluation are further:

- the improvement of the quality of the building with regard to the qualitative and quantitive requirements defined by the users and administrators, in particular with regard to improving comfort, a reduction in running costs and the maintenance of residential (and non-residential) buildings – saving energy, reducing water consumption, better use of primary materials
- the improvement in the quality of life thanks to a process of urbanisation that is respectful of the environment (criteria for organising public spaces, play areas, cycle paths, pedestrian and/or green areas, bus lanes) and a correct urban redevelopment of conurbation spaces;
- the control of mobility costs by means of economic and environmental management of the urban space to control urban mobility at different levels (quarter, city, conurbation).

It's in this sector of research and experimentation that we also find the efforts of the Italian Institute ICIE (Istituto Cooperativo per l'InnovazionE) which, since the '80s, has been studying the field of conserving the building stock, and which has invented and defined working instruments for the analysis and management of the built stock, intended as a "complex system", as a connected tissue made up of buildings, the spaces between them, equipment and service networks, where it is possible to operate in synergy and in an integrated manner.

2.3 *Multi-criteria analysis*

We've been able to observe how the decision-making system in relation to the transformation is influenced by multiple factors which we can define as level 1 (related to the deterioration and obsolescence of a building and the quality of its internal environment) and level 2 factors (environmental, social, temporal and economic). The distinction between the two levels, however, isn't sufficient to completely define the objectives of every single intervention: the objectives will depend in fact of the starting level of quality that's encountered and on the priorities at the outset for the definitive imposition of action.

Compromise, a fundamental means to identify an efficient solution, is to be sought in the typologies of social, technical, environmental and ecological factors, without overlooking the quality of the internal environment (such as dampness, acoustic isolation, comfortable levels of heating, air and ventilation quality, lighting, security) and of the external environment which should be pointed towards the user in so far as they are the beneficiary. Quantitative and qualitative information, which involves building systems and subsystems (described in units of measurement, value and initial conditions), completely define the reference variables on which to intervene through analysis, methods of verification and criteria for determining their value and importance. The theme of quality, therefore, in the intervention requires a clear carrying out both of all the aspects – measurable or not – and of their relative minimum values of acceptability, as well as a definition of the intervention strategies and the technical elements on which to intervene. The indicators, once they've been identified, form a whole which is able to structure the requisites that will be more able to interpret the needs that emerge and through which it'll be possible to verify the residual performances. Each of these, resulting from the analysis of problems that arise, is made up of subcategories which, in a more detailed and precise manner, define the performance deficits that are encountered, and, at the same time, represent the decision-objective inputs of the intervention.

The methodology described above was analysed and applied – in the context of research for a doctorate in Redevelopment and recovery at the Faculty of Architecture "Valle Giulia" of "La Sapienza" University of Rome – to a redevelopment intervention on a number of buildings in the residential complex "Le Navi" in Florence. The methodological-working instrument used in the research confirmed the validity both of the multi-parametric approach as well as of the qualitative results obtained through the intervention. Furthermore, the research reinforces the recognition of the coherence that exists between the qualitative aspects asked for and the solutions adopted, underlining the pre-eminence of the economic aspects in achieving the aims, but, at the same time, the knowledge that economic investment represents a fundamental parameter, but not for this reason one that should interfere with the possibility of an intervention. The instrument that's been arrived at, which doubtless needs to be adapted for future applications to other case studies, underlines on the other hand, the necessity, which we referred to above, of that continual and gradual movement towards the reality of actions that are peculiar to each transformation, seeking the common denominator in the approaches adopted, but recognising at the same time the uniqueness of each of these.

Today, but even more in the future, these residential complexes are and will be a part of history and, as such, we are responsible for their potential to a greater or lesser degree. Common needs of the past were faced up to in this way, with no regard for and not giving body to the culture and habits that are part of living somewhere. The relevance of these considerations calls for the need for a planning culture which avoids the possibility of falling again into the same traps as in the past.

REFERENCES

AICARR. 2006. *La certificazione energetica e l'efficienza energetica del sistema edificio impianto*. Milano: Aicarr,

Arbizzani, E., Civiero, P. 2007. *General overview of the problems, needs and solutions in the Italian urban building envelopes*. In Almeida M., Hadjmichael G., Melgaard E., Verhoef L.G.W. A (edit by), *Improving the quality of the existing urban building envelopes – Needs*. Amsterdam (Netherlands): IOS PRESS.

Battista, A., Tucci, F. 2000. *Ambiente e cultura dell'abitare. Innovazione tecnologica e sostenibilità del costruito nella sperimentazione del progetto ambientale*. Roma: Dedalo,

Caterina, G., Pinto, M. R. 1997. *Gestire la qualità nel recupero edilizio e urbano*. Rimini: Maggioli,

Civiero, P. 2007. *Habitus Habitandi/Habitus Re-Habi[li]tandi. Strumenti e metodologie per la riqualificazione degli edifici residenziali a tecnologia non tradizionale in Europa*, doctoral thesis in Redevelopment and recovery installation, XIX Cycle, at the Faculty of Architecture "Valle Giulia" of "La Sapienza" University of Rome

Civiero, P. 2006. *Riqualificazione dell'involucro dell'edificio.* In: Esposito M. A. (edit by). *Tecnologia dell'architettura: creatività e innovazione nella ricerca.* Firenze: Firenze University Press

CRESME 2005. *Il mercato delle costruzioni 2006. XIII Rapporto congiunturale*

Franco, G. 2003. *Riqualificare l'edilizia contemporanea*. Milano: Franco Angeli,

Gallo, C. 2000. *La qualità energetica e ambientale nell'architettura sostenibile*. Milano: Il Sole 24 Ore

Gasparolo, P., Talamo, C. 2006. *Manutenzione e recupero. Criteri, metodi e strategie per l'intervento sul costruito*. Firenze: Alinea

Ginelli, E. 2003. *Intervento sul costruito. Problemi e orientamento*. Milano: Franco Angeli,

Kroll, L. 2001. *Ecologie urbane*. Milano: Franco Angeli

Malighetti, L. E. 2004. *Recupero edilizio e sostenibilità*. Milano: Il Sole 24 Ore

Mork, O. C. et al. 2002. *Methods and tools for sustainable renovation of urban neighbourhoods*. In HQE2R Project

Pinto, M. R. 2004. *Il riuso edilizio. Procedure, metodi ed esperienze*. Torino: UTET

Sala, M. (edit by) 2001. *Recupero edilizio e bioclimatica*. Napoli: Esselibri

Turchini, G., Grecchi, M. 2006. *Nuovi modelli per l'abitare*. Milano: Il Sole 24 Ore

Turkington, R. et al. (edit by) 2004. *High-rise housing in Europe: current trends and future prospects.* Delft: University Press

Zambelli, E. (edit by) 2004. *Ristrutturazione e trasformazione del costruito*. Milano: Il Sole 24 Ore

UNI 11150-1/4. 2005. *Edilizia. Qualificazione e controllo del progetto edilizio per gli interventi sul costruito*.

Living Building Concept: new approach to value delivery in the built environment

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ABSTRACT: The “living building” concept (LBC) represents a new approach to the delivery and life cycle management of buildings. LBC is based on the fact that the function and circumstances of buildings are constantly changing. LBC aims to change the traditional demand-driven supply approach in construction into an approach of supply-driven demand involving all parties in the demand and supply system to develop an integrated product and dealing adequately with changing technology, regulations and demands throughout the life cycle. In order to do so the concept must be the basis for life cycle contracts, which is a result of a joint business case of both demanding and supplying parties maximizing the value on the one hand and minimizing the costs on the other. In two recent applications of LBC to education and healthcare buildings, LBC has indicated to be beneficial to develop buildings and the arrangement between client and supplier that are flexible in order to accommodate future changes.

1 INTRODUCTION

In construction, demand and supply of value can be a complex undertaking, particularly for large construction projects involving many parties and long lead-times. The main problem identified is the intrinsically dynamic character of the process, and the changing and often diverging perceptions of parties of the outcome of the process, versus the static approach to the control of the process, because of formal arrangements between parties. What is needed for the effective control of construction is an aggregate and comprehensive model to be able to dynamically and effectively control and adapt demand (clients’ value) and supply (delivery) in an integrated manner through the entire process, and idealistically through the whole life cycle of built facilities.

The “living building” concept (LBC) offers a conceptual solution to these problems. The concept is representing a further development of the concept of dynamic control that was introduced few years ago (De Ridder & Vrijhoef 2003). The concept is based on the essential notion that the world is changing. Secondly construction is a social activity: Construction implies complex product development in a changing context, involving many parties, delivering products with value to society, pulling high levels of resources from the economy. Construction projects often take a long time, and the life cycles of built services are lengthy. During the construction process, the level of information and knowledge grow, by both the client and the supplier. Demand and supply influence one another. So requirements of buildings change over time. Demand must be adaptable and supply must grow along. Procurement and supply strategies as well as project and life cycle management arrangements must be able to cope with these dynamic mechanisms. This calls for a reconceptualisation of the demand, delivery and life cycle management of built services.

2 AIM OF THE LIVING BUILDING CONCEPT

The rationale of the LBC is based on two underlying problems in construction: perception and ‘process statics’. These problems are caused by the fact that the first demand is basically always incorrect or incomplete, because it is impossible to demand before knowing what is available and possible. Supply without knowing at a basic level what is wanted is impossible also. So demand and supply are intrinsically connected, and this should be reflected in the process towards delivery of any product such as built services. However in current construction practice, this is often not the case. Demand and supply are relatively disconnected. This is basically the result of the tension between value and costs, and thus between the client’s interest in added value versus the supplier’s interest in profit.

The expectations what is a successful project are often subjective, implicit and contradictory. For many reasons there is always a need for some kind of change during the process, so there is a need for a dynamic approach. This is particularly true in construction, where there are often no formal rules, no strict hierarchy, no fixed product, parallel involvement of multiple parties, and the absence of one party who has complete overview and authority. However this depends on the procurement strategy and the contract type. The “natural response” in construction has been to try and fix and isolate various aspects as much as possible, including fixing the price and the design early in the process, which leads to quasi-certainty, process statics and disproportional additional transaction costs. Due to this kind of fragmented and delegated control, and long demand and supply chains, changes come often too late to be effectively and systematically dealt with. Change orders often take lots of effort to follow up leading to extensive amounts of rework or claims (Othman et al. 2004).

The problems of perception and process statics and the paradox between static control and dynamics of construction life cycles call for a dynamic and comprehensive approach to the demand and supply of built facilities, aimed at systematic and adaptive optimisation of the total life cycle benefit (total value minus total costs). When the total value could be interconnected qualitatively and quantitatively to the total costs of a built service, and parties agree on the algorithm between value and costs, then demanding and supplying parties collaboratively are able to deliver the highest possible benefit to the mutual advantage of both demanding and supplying parties (Vogtlander 2001) (figure 1).

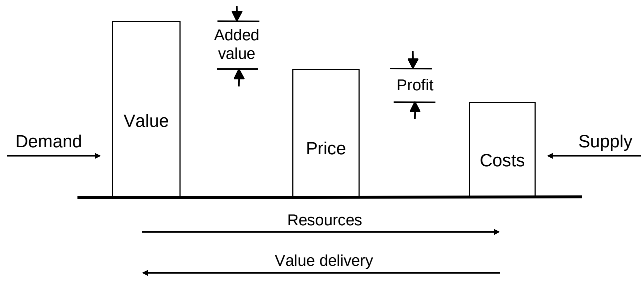

Figure 1: Basic transaction model between value, price and costs

3 DYNAMIC CONTROL TO INCREASE BENEFIT

Instead of enforcing the initial planned performance against a fixed price calculated in the first phase of the project, the price is based on the actually delivered performance at the end of the project. The final price goes up to the initially set maximum guaranteed price, not exceeding the planned budget of the client. The range between initial price and maximum budget is the client’s “control budget” for dealing with problems of perception and additional value to be delivered during the process. In addition, the contractor is able to reserve budget for investments to reduce costs or increase value (figure 2). This approach can be defined for the project only, but can be extended to the whole life, and can be applied to a variety of contract formats, from build-only contracts to more inclusive “DBFMOT” kinds of contracts.

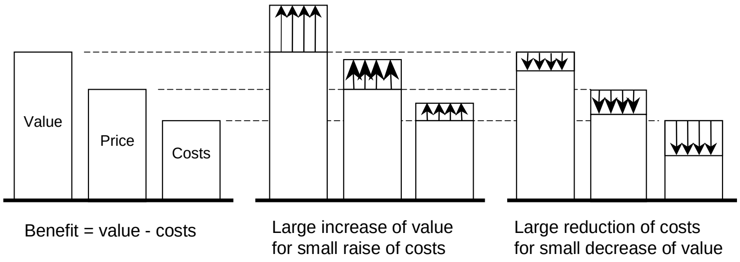

Figure 2: Dynamic control strategies to increase the total benefit

4 VALUE AND COSTS AS CHANGING VARIABLES IN TIME

The world and thus the built environment are changing while buildings themselves are static. A list of influencing factors can be given, which are subject to changes. First of all the users with their wishes and requirements. Then the surroundings with the associated stakeholders. Further, the regulations for what should be established and what is allowed in buildings change continuously. Then, the technology is in a constant acceleration. Also the climate is changing with rainfall, winds and temperature. Last but not least the financial situations are changing continuously. The changing world makes that a client should be aware of changing circumstances and changing insights which ask for 'living buildings'. Changes are regular instead of exceptions and should be incorporated in the contracts between demanding and supplying parties.

Nevertheless, an initiative for a construction or building project can be conditioned and limited in a first stage of a project. First of all the value should not be less than a certain minimum value. That defines the Design Program (Austin & Thomson 1999). The value is also limited by all types of boundary conditions, which together form a constraint. The difference between the minimum value and the actual value is limited by the boundary conditions which can be considered as a set of opportunities. Then, the costs should not exceed a certain maximum. That is the available budget. The initial estimation of the costs can be considered as a minimum. The reason is perception which in all cases leads to an underestimation of costs. The difference between the maximum costs and the minimum costs can be considered to be the "risk budget" (Figure 3).

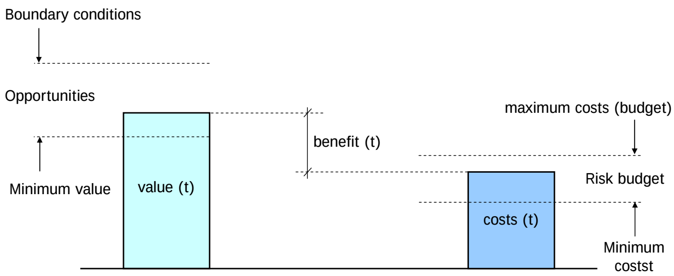

Figure 3: Essence of delivering value in the built environment

5 IMPLICATIONS FOR PROJECT ORGANISATION AND CONTROL

The main condition for dynamic control is the dynamic coupling between the three variables value, price and costs. In fact, two complex and multi-dimensional transfer functions should be established between value and price on the one hand, and price and costs on the other. The dynamic relation between the value and the price leads to a set of system specifications representing the system with value on the one hand and the price on the other. From the system specifications the client is to get an idea of the value, whereas the system specifications give the client the opportunity to pay a price for the delivered system. An exploration of the dynamic coupling between price and costs leads to the system (object, building, structure) itself as a mean to indicate the different cost types and the risk involved with the different tasks to be performed. For suppliers the difference between price and costs equals the sum of risks and profit (figure 4).

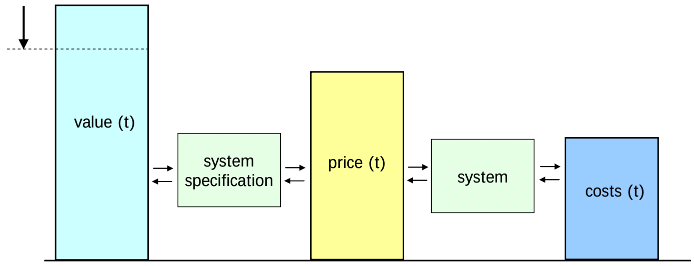

Figure 4: Dynamic coupling of value, price and costs

With the introduction of dynamic control the problem arises how to control the process. In fact for dynamic control the system behaviour at the top level should be quantified in value, price and costs, whereas the work will be done at the lower scale levels. A smart decomposition of the system can be helpful to reduce complexity and to improve control. Two types of part systems play an important role (De Ridder 1994). The first type is a subsystem, which is defined as a subset of elements of the system with conservation of all original relations between all elements. The second type is an aspect system which is defined as a subset of the relations of the system including all elements of the system (In ’t Veld 1992).

Subsystems refer to “things” and can be formed such that interactions and communications are simplified. (Kickert 1979). The “nearly decomposition rule” of Simon (Simon 1969) leads to the formation of subsystems. The consequence of this rule in terms of decomposition is that relationships inside the subsystems are maximised and relationships outside the subsystems are minimised.

Aspect systems refer to the issues or topics of a system and finally the behaviour of the system as a whole. It is clear that the costs at system level can be considered as aspect systems. For instance operational costs are a subset of the total lifecycle costs. It can be seen that a technical value as for instance “energy consumption” is also an aspect system. The same is true for a functional aspect such as pumping capacity for a pumping station. It becomes difficult for the “psychic value”. In most cases a reference building is used for aesthetic value or luxury level. When using aspect systems, value and costs can be controlled dynamically as well as top-down (figure 5).

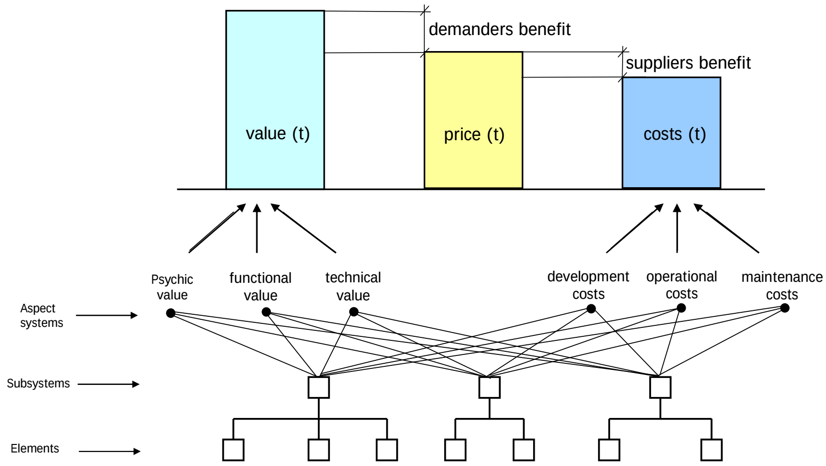

Figure 5: Simplified control of subsystems and aspect systems

6 IMPLICATIONS FOR CONSTRUCTION CLIENTS' PROCUREMENT

In the LBC approach the main issue for clients is to accept that value and costs are variables in time, set within a number of limitations but subject to the creativity and inventiveness of suppliers. Clients do so by defining an 'area of interest' rather than a fixed demand for a fixed price (Figure 6).

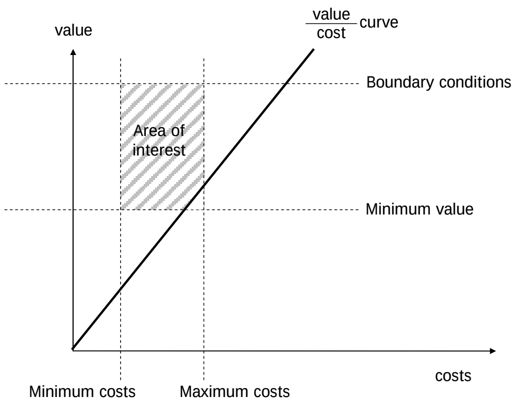

Figure 6: Client's area of interest

Based on the area of interest, the line C_1-P_1-V_1 in figure 7 represents system 1 delivered by supplier 1, characterised by Value V_1, Price P_1 and Costs C_1. The line C_2-P_2-V_2 represents system 2 delivered by supplier 2. It is easy for the client to determine the best "value for money". The supplier offering the system with the smallest alpha should be the winner in the competition. In the case of two suppliers both providers fulfil the basics requirements: $V_1 \geq V_{min}$ and $V_2 \geq V_{min}$ (figure 7).

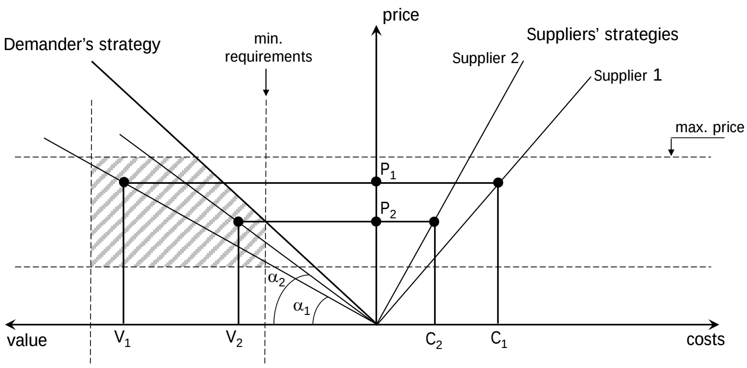

Figure 7: Selection of suppliers

The need for 'living buildings' requires a 'dynamic contract' in which the relation between value delivered and price to be paid is fixed. The simplest relation between value delivered and price to be paid is a straight line connecting the initial value-price proposal of the winning competitor with the origin. Hence any change in value can simply be quantified and thus paid for. However, the range and the impact of unforeseen changes must be limited. The boundaries of the changes are defined in the contract. In case changes appear to be too big, an additional contract will need to accommodate these changes. In most cases clients are willing to accept changes to the price up to a guaranteed maximum price (Boukendour & Bah 2001).

When a change occurs, it is easy to establish the actual performance of the system using the same aspect systems. First the aspect systems are made dimensionless and can therefore be considered as vectors. When using dimensionless linear vectors, it is possible to add the different value dimensions in order to establish a dimensionless total value. Then the ratio of the actual performance and the initial performance can be used to establish the price (De Ridder 2002).

Another way to arrange a coupling between the two variables value and costs is using scenarios. The client defines a few virtual and extreme scenarios with respect to psychic value, functional value and technical value which should virtually be realized 5 years after the start of the project. These scenarios are defined as a minimum and a maximum of the base case (figure 8).

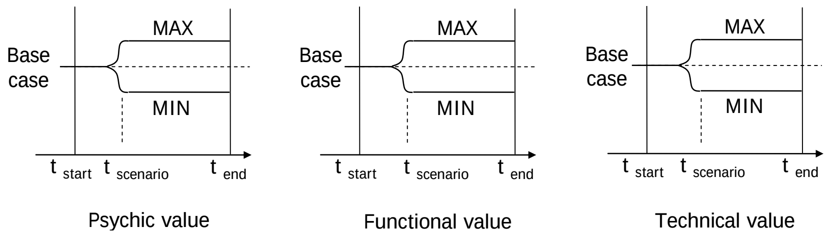

Figure 8: Minimum and maximum scenarios

The suppliers are invited to make a price for each scenario, which is rather simple because the scenarios are well defined. The price of an actual change can easily be determined from the scenarios, based on the magnitude of the change and the time if its occurrence, related to the scenario (figure 9).

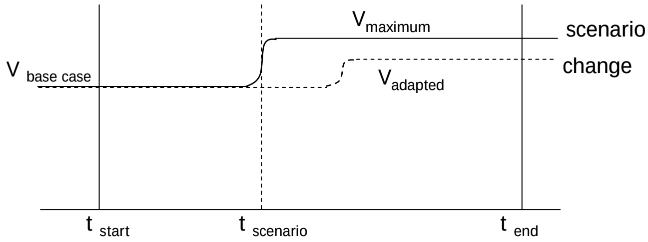

Figure 9: Change to the scenario

7 IMPLICATIONS FOR CONSTRUCTION FIRMS' DELIVERY

Suppliers are supposed to add value. This is only possible when they have full insight in the behaviour and the costs of their competitive offer. That means that they should sell only an aggregate of standard products belonging to product families and product modules, which result in a unique client specific solution. The development of product families is a result of market research and technical research. This is neither the case in the traditional situation nor in the DBFMO intermediate situation. The path towards a push market in the construction industry is shown in figure 10. A higher level of standardization will not only lead to better and cheaper solutions but also to significantly lower transaction costs when compared with the traditional situation. The difference is that the supplier will offer his own product, and possesses all related knowledge needed to supply the product.

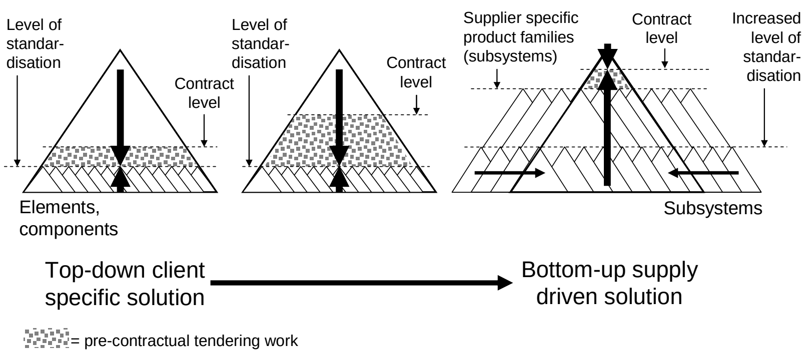

Figure 10: Path toward push market in construction

8 FIRST EXPERIMENTAL APPLICATIONS

8.1 *School building*

In 2006 an LBC experiment was done in the Netherlands on a school building. The experiment includes a dynamically controlled DBMO contract for a new school building. The client budget was 17 million Euro. The application of LBC encountered specific problems with the performance measurement and the way to make the actual performance reimbursable. The first task was to make an appropriate procedure in order to select and contract a contractor according to the principles of LBC. In addition, the procedure had to comply with European regulations.

The starting point for the school was a preliminary design which represented the present insight in the operations of the school, both in functions as well as processes. The client gave insight in a few possible scenarios, which were helpful for suppliers in order to make a design which was adaptive against low costs. Two scenarios were considered: (1) a functional scenario in which the building is portioned in a large number of rooms, which could be used autonomously with respect to the function, climate and energy consumption, (2) a technical scenario in which the installations (electrical, water supply, climate, waste water capacity, etc) were changed significantly. In addition, the design of the school building was fixed at the start. Suppliers are invited to present a school at one scale level lower than the preliminary design, give an initial price for their delivery, and to specify the aspect systems on which the value will be measured.

The final formation of performance aspect systems and the way they were to be measured were subject to contract negotiations, which took place after awarding the contract. These aspect systems played an important role as they were to reflect both the client's interests in the facility, as well as the contractor's and suppliers' cost profile in an acceptable way. The costs of the transformation itself were not incorporated in the lifecycle costs and thus the price to be paid for the total facility. However, an extra amount of money will always be charged in order to avoid too frequent changes. In that way a threshold will be built in to accommodate changes.

8.2 *Hospital building*

In 2006 LBC was applied to the redevelopment of an existing hospital which was built before in 1983. Due to changing policy by the national and local government, changing finances of healthcare, and increased commercial possibilities in the healthcare sector, the management of the hospital decided to rebuild the hospital and change it into a healthcare centre with multiple services added to it. Application of LBC has been studies for this particular case and indicated possible benefits, particularly because healthcare policies are bound to be changing further during the coming years. So this calls for flexibility of the building and the services in and around the new healthcare centre, and the contractual setting too. Besides healthcare demand and technology change fast. LBC has been particularly beneficial because it increases transparency and speed of the first phase of the project because all stakeholders are involved from the very start, and client requirements and wishes are captured in a minimum brief. In this particular case, a normal briefing process would have taken too much time. The LBC consortium was invited to deliver an integrated solution, the complete new building including all services and technology, and offering solutions to keep the building flexible. In order to increase the commercial possibilities and to ensure sufficient resources for the project, the main solution was found in physically disconnecting core facilities of the total centre from additional services, and reintegrating parts of them flexibly to the hospital. This enables the hospital to flexibly make use of the additional services, and enable them to deliver services to others at the same time too, which increases financial benefits.

The schedule for this project is rather tight, for redeveloping hospitals. In the first half of 2007, the brief will be developed further. By the Summer of 2007 the tender should be issued, in order to start construction by the end of 2007 or beginning of 2008. The entire project should be delivered in 2010. This requires a fast process, particularly at the start, to ensure parties to go ahead with their parts of the project, and be sure everyone understands the project, and feels comfortable with it. This was achieved by an 'integrated business case approach'. All demanding as well as supplying parties have partnered to find an optimal solution from both sides, optimizing the value-revenues-price balance from the demand side, and the value-price-costs balance from the supply side. Next both are brought together into a “life cycle transaction”, to conclude on an integrated business case by optimizing the value-revenues-price-costs balance over the life cycle for the total healthcare centre.

9 CONCLUDING REMARKS

LBC concept represents a new and comprehensive approach to demand and delivery of built services, based on a dynamic approach to the construction process and the life cycle. It solves problems of perception and process statics. It offers great potential advantages to demanding parties (clients, users etc.) as well as supplying parties (contractor, suppliers etc.). Particularly the continued dynamic approach, performance measurement and involvement of parties through the life cycle imply a great endeavour for clients as well as suppliers. After the first application of LBC to a school building, the application of LBC applied to a healthcare facility indicates that LBC seems beneficial here too. It is particularly beneficial because of the dynamic character of healthcare, caused by changing policies towards healthcare in general, and thus healthcare facilities and buildings in particular.

LBC enables the measurement of value and cost in projects during execution but also during the use of a building, determining when action should be taken in the case of changing scenarios which form a basis to plan and control the changes needed. When measuring the changed value using LBC, it also forms the basis of the associated price to be paid. As the suppliers will be invited to bid on a base case and predetermined scenarios, the risks are minimal. In consequence the transaction costs will be reduced significantly. In this way, LBC achieves its goal which is to maximise and balance the benefit for all parties at the end of a project and during the use phase, i.e. maximum added value for the client and maximum suppliers’ profits. The case of the healthcare centre has demonstrated that LBC is beneficial for healthcare facilities, particularly because of the dynamic character of healthcare demands and its context (interest of society, regulations, technology). LBC has offered solutions to cope with the changes and accommodate these in the built facility.

REFERENCES

Austin, S. A. and Thomson, D. S. 1999. "Integral value engineering in design." In: Proceedings COBRA 1999.

Boukendour, S. and Bah, R. 2001. "The guaranteed maximum price contract as call option." Construction Management and Economics 19, 563-567.

De Leeuw, A.C.J. 1974. Systeemleer en organisatiekunde, Leiden.

De Ridder, H.A.J. 1994. Design and construct of complex civil engineering systems: a new approach to organization and contracts. Delft University Press, Delft.

De Ridder, H.A.J. 2002. “Performance based control of design and construct contracts.” Proceedings CIB Joint Conference Hong Kong, May 2002.

De Ridder, H. and Vrijhoef, R. 2003. "The concept of life cycle benefit of buildings: developing a framework for life cycle value management." In: Proceedings CIB W055+065+107 Joint Conference Knowledge Construction, Vol. 1, 22-24 October 2003, Singapore, 654-664.

In ’t Veld, J. 1992, Analyse van Organisatie problemen, Stenfert Kroese, Leiden/Antwerpen.

Kickert, W.J.M. 1979. Organisation of decision making, North Holland, New York.

Othman, A. A. E., Hassan, T. M. and Pasquire, C. L. (2004). "Drivers for dynamic brief development in construction." *Engineering, Construction and Architectural Management* 11 (4), 248-258.

Simon, H.A. 1969. “The architecture of complexity”. In: The sciences of the artificial, Cambridge.

Van Emden, M.H. 1971. An analysis of complexity. Mathematical Centre, Amsterdam.

Vogtlander, J.G. 2001. The model of the Eco-costs/Value Ratio. Design for Sustainability Program, publication nr. 4. Delft University of Technology.

Measuring the effect of design changes by a neuro-fuzzy system

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ABSTRACT: After a building is put into use there is often a need for some improvements since a building's performance was unsatisfactory. In order to learn about building performance failures and to be able to propose necessary improvements, adequate building related data should be obtained. Data mining, which is also known as knowledge discovery, is extremely important for various fields since a lot of knowledge can be hidden in data. There are numerous relationships present between specific data items, which should be discovered with the appropriate methods. Data mining is slowly gaining on gravity in the architectural/design field as well. The application will be shown through a case study. In May 2000 a questionnaire regarding the perception of public safety and comfort at Rijswijk underground train station in the Netherlands was developed and distributed. Knowledge modeling was done using neuro-fuzzy system and sensitivity analysis was used to elicit knowledge from the knowledge base.

Based on the results of 2000, the underground train station was improved on several design issues. Six years later, the same questionnaire was handed out to measure the effect of change. In this paper, firstly case dtudy will be briefly explained followed by knowledge modeling by neuro-fuzzy system and knowledge elicitation by sensitivity analysis. Based on a questionnaire from 2006 and comparison with results of 2000, using data mining techniques, it is possible to measure the effect of a specific design change on a building's performance in terms of public safety and comfort.

1 INTRODUCTION

There are various reasons why a building undergoes changes after it has been put to use. Sometimes a building changes a user and therefore new set of requirements may appear. In other case, for example, a building's performance was not satisfactory in the first place. In this work we deal with the later one, since many buildings fail to meet the required performance and after a short period of being utilized are subject to the 'improvements'. Unfortunately, many projects and the issues related to their successful or unsuccessful use remain a hidden knowledge for a few directly involved or affected by it. This slows down the learning curve of the building industry. First issue is, the evaluation of a building in use happens rarely. Secondly, when the changes happen, those are again *ad hoc*. Also little is known forehand whether a decision made was a correct one and whether by changing perhaps another aspect a more desirable effect could be achieved. And finally, after a change is made, there is no systematic method into establishing the effect of change on a building performance. In this paper, based on one case study, a method will be explained that enables knowledge modeling and provides a focused approach to necessary design changes in order to improve building's performance. So what is a consequence of not having a proper knowledge management and knowledge modeling of buildings? When a performance of a building is not satisfactory and several improvements are carried out over the years to improve the performance, but lacking a real insight into the effect of change, sometimes a hasty decision is made to demolish a building. Occasionally whole neighborhoods are being demolished because the area seems to be publicly unsafe and therefore demolition seems to be ‘the best solution’ for solving the problem and replacing buildings by new design, which again does not guarantee a success. It goes without saying that such decisions can have an impact on the environment by producing additional building waste. It is very important to design in a way that future generations can adapt buildings for their own needs, meaning that way of constructing should provide some adaptation possibilities but even more, a building should have own electronic dossier, including a history of changes, the effects of changes, etc. This implies that there is a need to develop sustainable knowledge management of buildings so that it is possible to trace the changes and moreover to learn about their effects.

With this work we contribute to sustainable knowledge management regarding buildings and all changes that they undergo before they are demolished.

2 CASE STUDY: RIJSWIJK UNDERGROUND TRAIN STATION

The development of a framework for knowledge model and data collection and analysis in 2000 was a part of PhD thesis (Durmisevic, 2002). The PhD thesis considered in total four stations for cross-data analysis. In this paper, focus is only on one station, since this station did most of design changes so that a follow-up study could have been conducted in 2006.

As a case study, an underground train station in the Netherlands is considered. Rijswijk train station is a so-called linear station, meaning that there is only one train level without any exchange areas. The main entrance is located on a large square and the only visible aspect that suggests the presence of train station (Piramideplein) is the glass pyramid (*figure 1-left*). The other entrance is at Churchilllaan and its sides are also made out of glass to provide enough daylight at the entrance. The station is situated in a quiet area of Rijswijk, with mainly housing and offices nearby. Although the large shopping center is close to the station, this station remains isolated, with few visitors during day and night time, with exception of the rush hours (Durmisevic, 2002).

Figure 1: Main entrance at Piramideplein (left) and train platform (right)

The train platforms are very long (*figure 1-right*). and two entrances mentioned earlier are placed at the ends of the platforms.

In May 2000 a questionnaire regarding the perception of public safety and comfort at Rijswijk underground train station was developed and distributed. In total, after consistency and data quality analysis, 246 responses were used for knowledge modeling. In 2004/2005 some design changes followed. These changes were:

1. placement of the additional artificial lighting at underground train platforms to increase the overall lighting conditions (*figure 2*);

Figure 2: Lighting conditions in 2000 (left) and 2006 (right)

2. placement of the safety fences next to the stairways to avoid accidents if the elevators are used which are placed behind the stairs (*figure 3*);

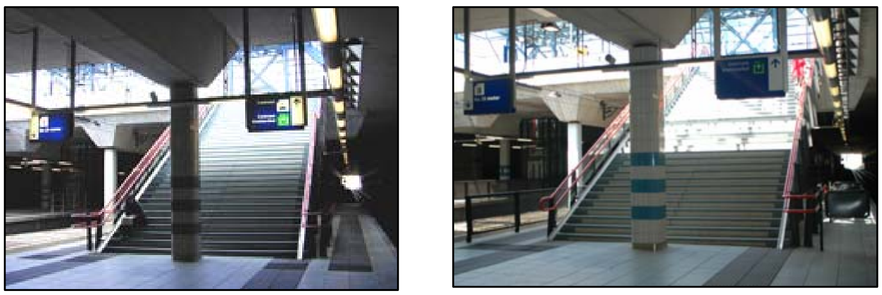

Figure 3: No safety fence in 2000 (left) and safety fence in 2006 (right)

3. placement of the hand-supports on the original benches at train platforms mainly to discourage homeless people to sleep on the benches (figure 4).

Figure 4: No hand-supports on benches in 2000 (left) and hand-supports in 2006 (right)

Next to these changes, which were mainly related to public safety, it is also important to note the following:

- due to poor drainage the station had more frequent problems with unpleasant odor and numerous stains on the walls and floor appeared; both of these issues were not the case in 2000;

- in 2000 the trains stopped close to the main entrance (Piramideplein) and in 2006 the trains stoped in the middle, between the two exits, meaning that no matter which entrance was used quite a long distance should be walked before reaching a place where the train actually stopped;

In July 2006 the same questionnaire was handed out and in total 303 questionnaires were used for knowledge modeling. The determinants, which are identified to be related to comfort and public safety are presented in *figure 5* (Durmisevic et al., 2001a). During knowledge modeling these two dimensions are studied together so that the unexpected relationships between any model components are taken care of without any loss of model performance

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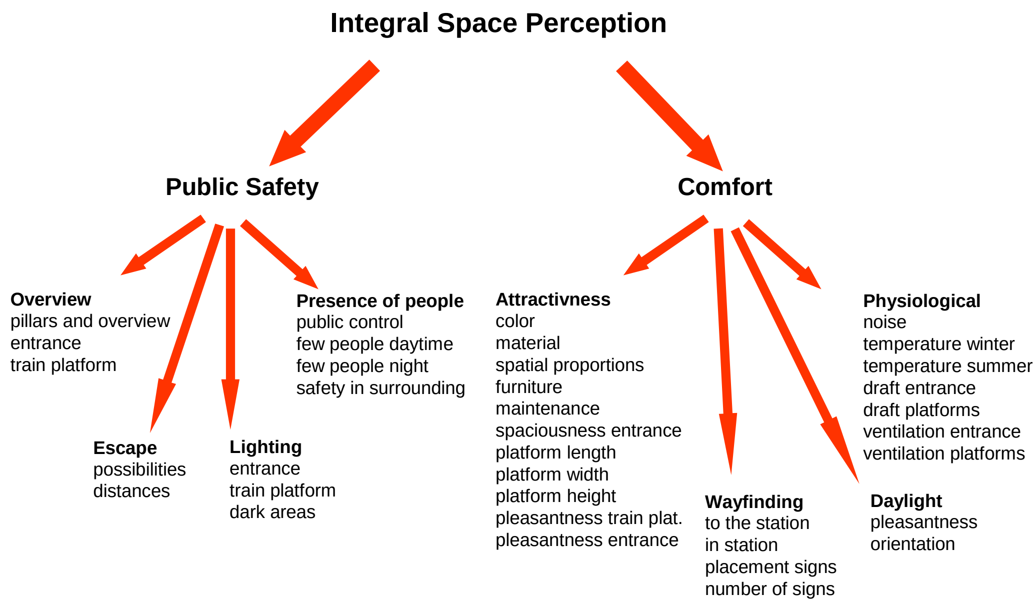

Figure 5: Aspects determining public safety and comfort in underground stations

3 NEED FOR KNOWLEDGE MODELING

The knowledge model in this research adapts the sequential information transformation steps such as *abstraction*, *association*, *classification*, *clustering*, *derivation* and *generalization*. One of the important advantages having such analytical knowledge model is the possibility of deriving further important knowledge from the model itself. Such derived knowledge from the established knowledge is referred to as meta-knowledge.

In general we can classify two types of knowledge: explicit and tacit knowledge. Explicit knowledge can be easily represented and applied due to its precise an unambiguous nature. It is mostly embedded in building standards, regulations and design guidelines. On the other hand, tacit knowledge, firstly introduce by Polanyi (1958), is much more difficult to represent, capture and reuse since it is generally fuzzy, ambiguous and imprecise. It is a knowledge of experts regarding specific domain. Modeling tacit knowledge is a time consuming activity and knowledge models can be either *data* or *expert* driven. In first case, data driven knowledge models rely on large amount of data where some data mining techniques are applied for knowledge discovery and elicitation. Expert driven knowledge relies on one person's/group of experts knowledge on a particular subject. This paper deals with the first one, data driven knowledge modeling.

In this research data is collected from users of the underground station on two occasions. One in 2000, in order to obtain a reference point (0-measurement) for any changes occurring afterwards. The second data collection was in 2006, after some design changes were actually realized on a station. The purpose of second data collection was to measure the effect of design changes on a total building's performance in terms of public safety and comfort.

As it can be seen in *figure 5* the data at hand is qualitative and imprecise. This implies that special techniques, able to deal with 'soft' data, are required. In this work a combination of the Artificial Neural Network and Fuzzy Logic (Zadeh, 1965) is applied for knowledge modeling. This needs some further explanation.

Buildings are complex environments rich in information and to establish the complete fuzzy rules dealing with the knowledge base is a remarkable task. To reduce the problem, the knowledge base can be formed in a distributed and structured form by means of learning so that the structure so formed represents the fuzzy expert system altogether with the consistent rules in any complexity. Here the main task for consistent rules is to carry them out by means of learning process, which should be specially designed for this purpose. The accomplishment of this structure can be achieved by means of a network operating with fuzzy computational units. Such structure can be a radial basis function network (RBFN). The general characteristics of such network are rather diverse and comprehensive with sound mathematical foundations. On one side they can be considered as multivariable multifunctional approximators using basis functions (Broomhead and Lowe, 1988) with functional interpolation and extrapolation capabilities. On the other side they are equivalent to fuzzy logic systems under some lenient conditions (Roger, 1990; Hunt, 1998). Due to these properties, conversely fuzzy logic systems can be used as universal approximators (Kosko, 1994; Wang, 1994). The general structure of a RBFN is shown in *figure 6.*

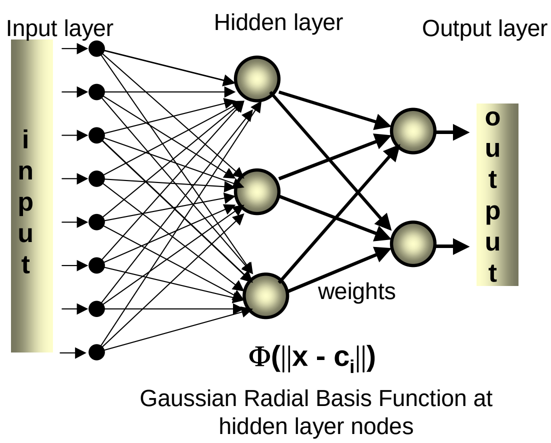

Figure 6: Radial basis function networks for knowledge modeling

Without loss of generality, the number of outputs in the network can be extended to a multi-output case. In this research there are two dimensions at the output space (comfort and public safety). The network architecture consists of an input layer, a hidden layer and an output layer. The hidden layer consists of a set of radial basis functions as nodes. Each node has a parameter vector **c** defining a cluster center dimension of which is equal to the input vector. The hidden layer node calculates the Euclidean distance between the center and the network's input vector. The distance calculated is used to determine the radial base function output. Conventionally, all the radial basis functions in the hidden layer nodes are the same type and usually Gaussian. The response of the output layer node(s) can be seen as a map f: $R^n \rightarrow R$, of the form

$$f(\mathbf{x}) = \Sigma\, w_i\, \Phi(||\mathbf{x} - \mathbf{c}_i||)^2$$

Here the summation is over the number of training data N. $\mathbf{c}_i$ (i=1,2,….N) is the i-th center which may be equal to the input vector $\mathbf{x}_i$ or may be determined in some other way. Once the basis function outputs are determined, the connection weights from hidden layer to the output are determined from a linear set of equations. As a result, accurate functional approximation is obtained. The complexity increases as the size of the training data increases. For a large data set, this may become unpractical, and therefore it is desirable to use limited number of hidden layer nodes in place of having a number equal to N.

The mathematical model employed is a multivariable functional approximation structured in a neuro-fuzzy knowledge representation form. The advantage of such structure is that the knowledge can be effectively modelled by such system with appropriate learning strategy.

Such form, is compatible with a fuzzy logic structure as the radial basis functions play the role of fuzzy membership functions (Cios et al., 1998) and the output is a fuzzy decision-making based on the soft (fuzzy) architectural design data. In particular, the machine learning method used is orthogonal least squares (OLS) method (Chen et al., 1991), which is the essential requirement to use for machine learning in this particular knowledge modeling research (Dirmisevic, et.al, 2001b).

Having finalized the knowledge modeling, the sensitivity analysis is carried out. The sensitivity analysis is a method used for determining the dependency of the output of a model on the information fed into the model. In other words, sensitivity analysis "studies the relationships between information flowing in and out of the model" (Saltelli, et. al., 2000). The whole procedure is summarized in *figure 7*.

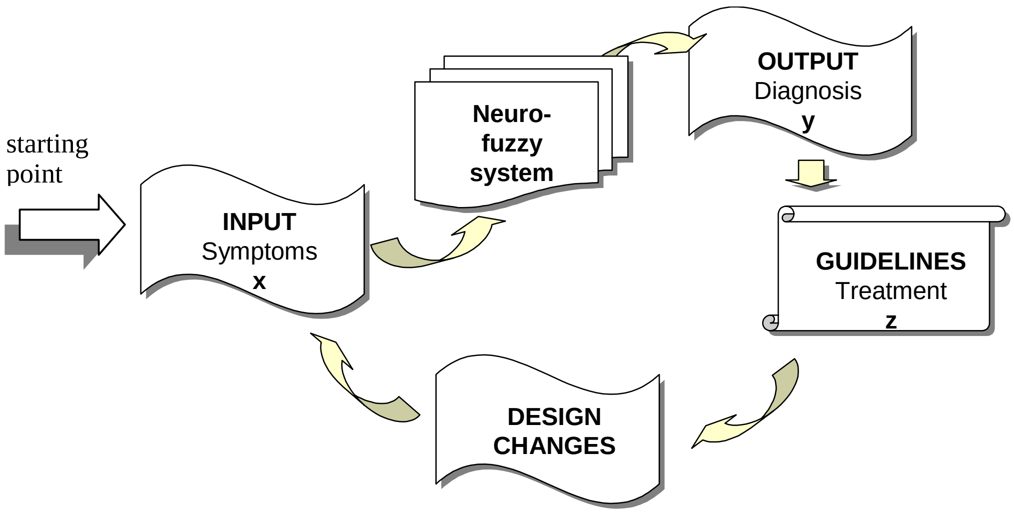

Figure 7: Towards a sustainable knowledge management of building information

As it was mentioned earlier, in order to measure the effect of change it is first of all necessary to conduct a 0-meassurement where data is obtained for the first time. The main characteristics of a building represent input for a model and final outputs can be seen as a diagnosis of a building, which in this case represents a performance in terms of public safety and comfort. A neuro-fuzzy system is used to match input with the output and establish the weights. Thereafter, based on sensitivity analysis the treatment/improvements can be suggested, which are based on the knowledge model outcomes. From this point changes can be realized and later on the same loop is run. In this way the changes and the effect of changes are efficiently recorded and managed. This can help construction industry to learn faster about successes and failures of particular buildings, their context and set of constrains.

4 KNOWLEDGE MODELING AND RESULTS

In 2006 there were in total 303 cases used for knowledge modeling. The actual data and training data are given in figure 8. We have used 80 hidden nodes which best represents the current data. Having modeled the knowledge it became obvious that very few cases were present for the 0.9 range for comfort estimate, meaning that very few people found the station successful in terms of comfort (only 2.31%). If any predictions were to be made for the 0.9 range than it could be expected that the errors would be higher, than for predictions between 0.1 and 0.7. It is possible to exclude the 0.9 range but the experiments showed that the model performance for other ranges did not significantly improve.

Having trained the network, sensitivity analysis was used to establish the relative importance of aspects in relation to public safety and comfort. In *table 1* and *table 2* only the top 5 aspects are shown for the year 2000 and 2006.

Table 1: The hierarchical order of sensitivity analysis results for safety for Rijswijk station for the year 2000 and 2006

Hierarchical order 2000 for safety	Hierarchical order 2006 for safety
1.safety in surrounding	1. safety in surrounding
2.few people during night	2. pleasantness daylight
3.few people daytime	3. few people daytime
4.ventilation of entrance	4. placement of direction boards
5. number of signboards	5. noise

Table 2: The hierarchical order of sensitivity analysis results for comfort for Rijswijk station for the year 2000 and 2006

Hierarchical order 2000 for comfort	Hierarchical order 2006 for comfort
1. pleasantness train platform	1. pleasantness train platform
2. spatial proportions	2. maintenance
3. safety in surrounding	3. platform width
4. overview of entrance area	4. placement of direction boards
5. platform height	5. pleasantness daylight

Figure 8 shows a comparison of building performance for public safety and comfort for different year periods. Comparing the average grades, a 10% increase in the perception of public safety is observed while at the same time a 10% decrease in the perception of comfort is observed.

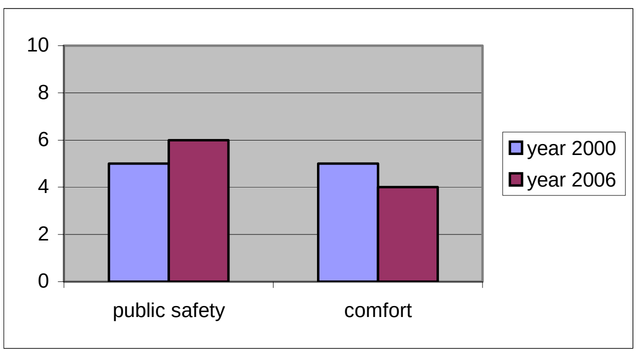

Figure 8: The average grade for public safety and comfort for the year 2000 and 2006

Improving the light conditions, placing safety fence and placing hand-rails on the benches had an accumulated effect and improved the performance of a building in terms of public safety by 10%. On the other hand, neglecting issues related to comfort, such as for example the maintenance issue related to poor drainage and bad odor had a negative impact and therefore resulted in 10% decrease of buildings performance in terms of comfort. Since maintenance is neglected a much higher costs can be expected now in order to repair the damage.

5 CONCLUSIONS

This paper demonstrated a methodology developed for efficient knowledge management and knowledge modeling of building performance in terms of public safety and comfort. Using neuro-fuzzy system together with the sensitivity analysis showed to be a good indicator of the ‘pain points’ in the buildings and also provide means to measure the effect of change on the building performance taking into account the presence of all other aspects at the same time. It is difficult to imagine how the change of one aspects can effect the performance and perception of other aspects in the model. The methodology explained in this paper shows a way to better understand the effect of changes and to approach the 'improvements' in a more responsible way.

With this work we contribute to sustainable knowledge management regarding buildings and all changes that they undergo before they are demolished. It helps the design community and construction industry lo learn faster about successes and failures of building performances and therefore work towards more sustainable built environments which do not require such frequent changes due to performance failures.

6 REFERENCES

Bhatti, M. A., 2000, *Practical Optimization Method.* Springer-Telos, ISBN 0-387-98631-6, Berlin

Durmisevic, S., 2002, Perception of underground spaces using intelligent knowledge modeling. PhD thesis, Delft University Press, Delft, The Netherlands

Durmisevic, S., Ciftcioglu, Ö. and Sariyildiz, S. 2001a. Quantifying the qualitative design aspects, *Conference proceedings ECAADE*, 28-31 August 2001, Helsinki, Finland

Durmisevic S., Ciftcioglu Ö. and Sariyildiz S. 2001b. Knowledge modelling of 'soft' data in architectural design, *Proceedings of the CIB-W78 International Conference: IT in Construction in Africa 2001*, CSIR, Pretoria, South Africa, 14.1-14.13.

Durmisevic, S., Ciftcioglu, Ö. and Sariyildiz, S. 2001a. Quantifying the qualitative design aspects, *Conference proceedings ECAADE*, 28-31 August 2001, Helsinki, Finland

Saltelli A., Chan K. and Scott E. M., (Eds.), 2000. *Sensitivity Analysis*, Chichester: Wiley

Broomhead, D.S. and D. Lowe (1988). Multivariable Functional Interpolation and Adaptive Networks, *Complex Systems, 2, pp. 321-355*

Chen S, C.F.N. Cowan and Grant, P.M. 1991. Orthogonal Least Squares Algorithm for Radial Basis Function Networks, IEEE Trans. on Neural networks, Vol.2, No.2, March

Cios K, Pedrycz W and Swiniarski R. 1998. Data Mining Methods for Knowledge Discovery, Kluwer Academic Publishers, Bosto/ Dordrect/ London

Hunt K.J., Haas R. and Murray-Smith R. 1998. Extending the Functional Equivalence of Radial Basis Function Networks and Fuzzy Inference Systems, IEEE Trans. on Neural Networks, Vol.7, No.3, May

Kosko B. 1994. Fuzzy Systems as Universal Approximators, IEEE Trans. on Computers, Vol.43, No 11, November

Polanyi, M. 1958. *Personal Knowledge: Towards a Post-Critical Philosophy*. Chicago University Press, Chicago

Roger J.S. and Sun C.T. 1990. Functional Equivalence between Radial Basis Function Networks and Fuzzy Inference Systems, IEEE Trans. on Neural Networks, Vol.4, No 1, January

Saltelli, A. 2000. *Sensitivity Analysis.* Edited by Saltelli, A., Chan, K. and Scott, E. M. John Wiley & Sons Ltd, West Sussex

Zadeh L.A. 1965. *Fuzzy sets*. Information and Control 8, 338-353

Wang Li-X. 1994. Adaptive Fuzzy Systems and Control, PTR Prentice Hall, Englewood Cliffs, New Jersey 07632

Early design stage evaluation tool for sustainable energy systems in large new buildings

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ABSTRACT: The paper outlines a new online planning assessment application for assessment of 13 different sustainable energy technologies for large new buildings. Key factors that influence the performance of each technology are outlined highlighting typical values and ranges set for user adjustment. The overall structure of a 3 level qualitative and quantitative assessment procedure will be presented along with the methodological framework of early design stage contextual constraints between generic building types and technologies.

1 INTRODUCTION

The successful implementation of sustainable energy systems (SES) in new building development projects involves consideration of integration and performance related issues from the earliest design stages through to installation and commissioning. In the earliest design stage when the design concept is being developed identification of key issues affecting the suitability of SES to a project and the types of impact of these have on other building design aspects are needed quickly. As design development moves onto the initial detailed design stage, when costs are typically being set, the costs and benefits of SES need to be evaluated. This evaluation is mainly site or project specific. Therefore through early design stages of a project the type of information needed to inform decisions evolves from being qualitative to being more quantifiable.

To address this evolution of information needs and better inform design teams on the implications of successfully using SES and also meet the requirements of Article 5 of the Energy Performance of Buildings Directive (EPBD) (Anon. 2002), in large new building projects, the Sustainable Energy Authority of Ireland (SEI) commissioned a national study of alternative energy systems, i.e. equivalent to SES. This resulted in the development of an online application, which is an evaluation tool for early design stages, called the Planning Assessment Software for Sustainable Energy Systems (PASSES).

The PASSES online application is a dynamic website based tool hosted online where registered users have access to a three level evaluation tool and a wide range of information on 13 different SES. This paper outlines the structure and functionality of the evaluation element of this application as well as the methodological frameworks developed to distill the types of information needed to inform early design stage decision making.

2 SUSTAINABLE ENERGY SYSTEMS

There are a wide range of sustainable energy systems in the market with new ones under development for future wider commercialisation, e.g. fuel cells. Many SES currently in the market

have been commercially available for many years and have been subject to product refinement to achieve optimum performance and robustness; these can be considered technologically mature. Essentially SES are designed to provide a more sustainable solution to meeting some type of energy end use demand in a building, as follows:
- Heating
- Cooling
- Power (electricity)
- Combined

Within each of these categories SES deliver the type of energy from a natural resource, e.g. solar, wind, flowing water or low grade heat, or a renewable fuel, e.g. biomass, biogas or waste heat from other processes. The suitability and performance of SES therefore is generally a function of the availability of a resource or fuel and matching of the availability profile with the demand profile of an energy end use. The former is driven by a project and sites context and the latter by building function, usage and thermal performance.

The SES were selected, see below, for inclusion in the online application/tool to reflect the Irish context, in terms of renewable resources and fuel availability, and the main energy end use categories in the national stock of new buildings over 1,000m^2.
- Biogas
- Biomass heating
- District or block heating
- Heat pumps
- Solar water heating
- Absorption cooling
- District or block cooling
- Photovoltaic
- Wind
- Combined Heat & Power (CHP)
- Biomass CHP
- Combined, Cooling, Heat & Power (CCHP)

2.1 *Heating*

The size of SES in the heating category is a function of the total heating demand. This is derived from building annual unit energy end use demand and floor area for a conventional gas, oil or electric heating system and the typical cost effective proportion of this demand to be met by the SES, resulting in a sizing estimation of each SES. The parameters influencing this sizing estimation vary for each SES.

The main factor influencing the performance and therefore size and associated CO2 emissions of biogas heating plant, anaerobic digestor type, to meet the calculated annual energy demand is seasonal efficiency. This is typically equivalent to that of a conventional gas boiler, i.e.73%. As feedstock supply costs can vary widely the assumption is made that a gate fee is charged such that the operator does not have to pay for waste type feedstock.

Biomass heating requires the purchase of biomass fuel, e.g. pellets or woodchips, which varies depending on type and scale of delivery, see Table 1 below.

Table 1 Biomass fuel unit costs

Biomass fuel	Unit cost (€/kWh)
Commercial scale wood chips (max. 25% moisture content)	0.027
Commercial scale wood pellets (bulk delivery)	0.036
Commercial scale wood pellets (bagged)	0.056
Domestic scale wood pellets (bulk delivery)	0.034
Domestic scale wood pellets (bagged)	0.064

The CO_2 emission benefit of biomass fuels is complex but is mainly influenced by delivery distance. For example, where biomass fuel is sourced from within 40km of the building it can be considered, on balance, to have zero CO_2 emissions, whereas a factor is applied if the distance for delivery is greater. The default factor adopted is 0.00014kgCO2/kWh.

Whilst the main advantage of district or block heating is the opportunity for economies of scale that enable use of large scale renewable heat sources the centralized energy centres of these are typically direct equivalents to combined heat and power (CHP) plants which are dealt with in more detail in the 'Combined' section of this paper. However, in addition to this district or block heating in comparison with local heating systems have the advantage of higher seasonal efficiencies, e.g. up to 90%.

Heat pumps essentially provide a more efficient use of electricity than conventional electric heating resulting in lower CO_2 emissions. The two main types of heat pump are ground source and air source with coefficients of performance of 2.0 and 4.0 respectively. The main difference in heat pump costs and benefits is due to the proportion of the buildings total heating demand that can be met. For ground source type heat pumps this is constrained by available land area, and similarly the length of the ground loop determines the amount of parasitic energy consumed by a circulating pump, therefore length factors are included for different horizontal and vertical ground loop situations, see Table 2 below.

Table 2 Ground loop length factors

Ground loop type	Underground type	Length factor (m/kW)
Horizontal	Moist, cohesive soil	22
Horizontal	Water saturated sand or gravel	14
Vertical	Poor underground (dry sediment)	40
Vertical	Normal underground and water saturated sediment	17
Vertical	Consolidated rock	12

As optimal, cost effective application of a solar water heating system will typically result in meeting 50% of hot water demand in Ireland, this is the target set for calculating system size, cost and CO_2 savings. Under optimum building integration, i.e. orientation and tilt, the nominal annual output of collector arrays are within the range 450 to 800kWh/m^2. This output is affected by collector type, orientation, tilt and shading. Therefore, calculation of nominal output provides for user selection for each of these.

2.2 *Cooling*

The size of SES in the cooling category is based on the total cooling demand derived from building annual unit energy end use demand and floor area for a conventional electric vapour compression chiller with a COP of 3.0. The factors influencing the sizing and CO_2 emission savings vary for each SES.

As the average coefficient of performance (COP) of an absorption cooling system, e.g. 1.0, is one third of that of a conventional electrical vapour compression unit, e.g. 3.0, the greatest CO_2 saving benefit is achieved by harnessing a nearby waste heat stream, e.g. from a nearby industrial process. Additionally, the most significant factor in both the COP and capital cost is whether the system is a double or single-effect type. Both these aspects of absorption cooling costs and benefits are accommodated explicitly in the calculation set with user selections available.

The main comparative benefit of district or block cooling is economies of scale, similar to those for district heating, which result in enhancing the economic viability of centralised absorption cooling plants. Due to large scale of district or block cooling systems only double-effect absorption cooling types are available in this calculation set.

Ground coupled cooling systems make use of either aquifers or underground air labyrinth's as free cooling or low grade heat sources. The potential for CO2 emission reduction is significant where for example aquifer based cooling has typical COP of 10. Optimum cost effective application of either of these produces different amounts of cooling and therefore different proportions of total cooling demand, i.e. 100% and 50% respectively. This is mainly due to the typical COP and seasonal peak thermal heat capacity of each, i.e. aquifer 10 and 50W/m^2 and air labyrinth 7 and 25W/m^2 respectively. These performance factors are explicit in the calculation set.

2.3 *Power (electricity)*

Calculation of the costs and benefits of SES in the power category are based on the baseload electricity demand derived as a nominal proportion of total electricity demand based on building annual unit energy end use demand, i.e. cooling, fans & pumps, lighting and other electric, and floor area. The parameters influencing the sizing and CO2 emission savings vary for each SES.

Photovoltaic (PV) systems have a large range of performance characteristics that vary across the different types available. Primarily these include rated output per unit area and annual output per unit of rated output, which are a function of PV type and solar resource access, e.g. orientation, tilt, overshadowing, and balance of system components respectively. Each of these factors can be user selected from a range of default values.

Wind systems in building projects can be either of the small, building integrated scale or medium to large stand-alone turbine scale, each having different unit capital costs, e.g. €3,500/kWe to €7,500/kWe respectively. This is the main difference as effective power output is more scalable and more significantly influenced by site characteristics such as average wind speed, consistency of direction and local turbulence. Each of these site characteristics can be adjusted individually by the user.

2.4 *Combined*

Calculation of the costs and benefits of SES in the combined category are based on an heat led approach to sizing and therefore centre on the baseload heating demand derived from building annual unit energy end use demand and floor area. The parameters influencing the sizing and CO2 emission savings vary for each SES.

The three main types of combined heat & power (CHP) are conventional fuel, biomass and combined, cooling heat & power (CCHP). The main differences in costs and benefits between each are a function of the heat load diversity factor, optimum annual operating hours, overall seasonal efficiency and unit capital cost as tabulated in Table 3 below. These parameters can be adjusted within predefined ranges by the user.

Table 3 CHP main variations of economic and environmental performance parameters

Performance parameter	CHP	Biomass CHP	CCHP
Heat load diversity factor (%)	70	50	60
Optimum annual operating hours (hrs)	4,000	8,000	6,000
Overall seasonal efficiency (%)	85	85 (wood pellets) 75 (wood chips)	85
Unit capital cost (€/kWe)	1,150	4,000	1,250

3 STRUCTURE

The PASSES evaluation tool has a three level structure, Level 1, Level 2 and Level 3, designed to reflect the different types of information both available and needed to inform decision making at the options, outline and initial detailed design stages. The guidance and outputs from the tool are based on the two core information and data elements of buildings and technologies (i.e. SES).

Levels 1 and 2 are based on qualitative characterisation of building energy demands and design aspects that impact on successful integration of SES and characterisation of the primary factors influencing suitability of SES to a building. Level 1 and 2 outputs are based on green, amber and red flags for each combination of building type(s) and SES. The flags represent high applicability, general applicability and not likely to be applicable respectively.

Level 3 provides quantified output based on economic and environmental performance calculation sets. This level is designed to produce output that can be used to readily evaluate the costs and benefits of design options that include appropriate SES. The outputs of this level see Table 4, can be used directly to inform design decisions during the initial detailed design stage.

Table 4 Level 3 output metrics

Level 3 metric	Unit
Capital cost	€
Annual CO2 saved	tonnesCO2/yr
Annual fuel cost saving	€
Simple payback period	Yrs
Net Present Value	€
Internal Rate of Return	%
NPV per unit of annual CO2 saved	€/tonneCO2

4 QUALITATIVE GUIDANCE

Level 1 provides a comparison of the building specific and SES specific characteristics with minimum inputs from the user, i.e. building type(s) and floor area only. This is reflective of the earliest stage of a buildings' design where the main information known about the project is type or function and approximate size. Providing an early indication of the suitability of SES enables designers to include these types of solutions within their design criteria as the concept develops.

Qualitative characteristics of generic energy demands and generic system integration issues were developed for 44 of the most common large new building types in Ireland, see examples in Table 5 below. Similarly, qualitative characteristics of SES building application were developed for each of the 13 SES, see biogas example in Table 6 below. Level 1 output flags are based on a cross-referencing of building type characteristics and SES applicability characteristics.

Table 5 Example building type qualitative characterisation

Building type	Generic energy demand	Generic system integration
Civic - Courts	Medium power demand, medium space heating, minimal cooling, small HW; profile is daytime peak; not weekends	May be land area (car parks), large roof area, possibly space for plant, limited staff availability.
Civic - Garda HQ and Control Centres	Medium demand for power, space heating and cooling; limited HW demand; profile 24/7 with daytime peak	May be some land area, large roof area, may be space for plant, limited staff availability.
Civic – Libraries	Small/medium demand for power, space heating, some cooling, limited HW; profile mainly daytime and evenings, 6 days/week.	May be some land area (car parks), medium/large roof area, may be space for plant, limited staff availability.

Table 6 Example Biogas applicability qualitative characterisation

Applicability	SES building application
GREEN	building types with high and constant heating/hot water requirements (in heating season at least) and a reliable feedstock supply
AMBER	building types with medium and fairly constant heating/hot water requirements (in heating season at least) and a reliable feedstock supply
RED	building types with low or highly unpredictable heating/hot water demands or unreliable feedstock source

Level 2 is effectively a refinement of Level 1 where more detail on relevant characteristics of the site and project, see Table 7 below, are used to determine the most suitable SES. Completion of this level enables users to identify and include any provisions necessary in the building design process to accommodate particular SES. An example of this would be the inclusion of rooftop panels in drawings submitted for outline planning to accommodate solar water heating. Level 2 asks the user a series of contextual questions which have an impact on both resource and fuel availability and potential for building integration. Where relevant the user's answers to these questions causes an adjustment of the flags output for each technology, see Table 8 below.

Table 7 Site and project contextual characteristics

Primary issue	Secondary factor
District heating	Site heating networks
Solar	Orientation
	Shading
Wind	Turbulence – small, building integrated turbines
	Turbulence – medium to large stand-alone turbines
Floor space	Plantroom
	Fuel storage and management
Site geology	Site hydrology
	River or stream
	Weir
	Canal/lake/reservoir
	Aquifer
Biogas feedstock	None
Waste heat	None
Designated areas (e.g. national park etc.)	None

Table 8 Example Level 2 contextual questions and resultant flag adjustments

Question	Question text	SES applicable to	Yes	No	Not sure
Orientation	Will the building(s) have a roof area oriented between south-east and south-west, or a flat roof? If not, can it be orientated so it will?	solar PV; Solar water heating; solar space heating	no change + prompt Q2.1	change to amber + reduce energy output of solar systems by 20% + prompt Q2.1	no change + address cautionary note + prompt Q2.1
Shading	Will or can the roof area be generally free from overshadowing for most of the day from other buildings or structures?	solar PV; Solar water heating; solar space heating	no change	change to amber + reduce energy output of solar systems + show cautionary note	no change + address cautionary note

5 EVALUATING ENVIRONMENTAL AND ECONOMIC IMPACTS

Level 3 provides quantification of the environmental and economic costs and benefits of appropriate SES to the building type(s) selected by the user. This evaluation adresses the key factors that affect the economic and environmental performance of each of the SES listed in Table 2 above. These factors include general and technology parameters as well as building annual energy end use demands.

General parameters are those which are common for all SES and include retail prices for energy and fuel, CO2 emission factors, annual operational hours for heating and cooling and financial forecasting, e.g. discount rate. These values are set centrally by the website administrator.

Building annual unit energy end use demands (kWh/yr/m^2) were developed for each of the 44 building types. These were derived by deconstructing available existing energy consumption benchmarks for, where possible, each end use and fabric and system performance standards in use at the time of original publishing and then reconstructing for 2006 regulatory standards[1]. This process produced a series of new minimum annual energy end use consumption benchmarks that are used as default values in the Level 3 calculations. However, the user is also provided with the option of either inputting their own values or selecting good practice, best practice and advanced energy standards which result in adjustment of the minimum energy consumption figures by the predefined factors tabulated in Table 6 below.

Table 6 Building end use energy demand adjustment factors

Energy end-use	Delivered heating	Delivered DHW	Space cooling	Fans & pumps	Lighting	Other electric
Good practice	20%	10%	5%	5%	10%	5%
Best practice	40%	20%	10%	10%	20%	10%
Advanced	60%	30%	15%	15%	30%	15%

Generally, the main performance requirements are calculated for each SES technology; see sections 5.1 to 5.4 below, and an equivalent non-sustainable or conventional system, e.g. electric vapour-compression chillers, to enable estimation and comparison of costs and CO2 emissions. This framework is based on those developed in the London Renewables Toolkit (Anon. 2004) but that has been developed to provide an additional degree of site and SES specific characteristics.

The difference in energy consumption, primary fuel costs and resultant CO2 emissions are then calculated. For example, the CO2 savings from use of a solar water heating system depend mainly on the amount of conventionally heated hot water offset by the system plus any emissions resulting from parasitic energy consumption, e.g. a circulating pump. This involves estimating the yield from a solar water heating system as a function of solar access, panel type and hot water demand due to building type.

6 CONCLUSION

The paper has outlined the structure and content of a multi-stage design tool for the evaluation of SES in large new buildings. The development of this has been shown to accommodate both qualitative and quantitative characterisation of SES and buildings to support the evolution of information availability and needs as a building design develops from the earliest stages up to initial detailed design.

The online evaluation tool described provides a useful framework for further development of detail in either building energy demands or SES performance characteristics that become increasingly important as a design develops beyond the stage of initial detailed design. A key value of the tool is the breadth of issues covered in a single source and the ability to compare issues, implications, costs and benefits across the full range of appropriate technologically mature SES in Ireland.

The structure and online basis of the tool provides an easily accessible resource with clear rules of thumb type guidance and calculated outputs to inform and support design making on the use of SES in buildings. The transparency of the tool will result in added value to the user where repetitive use will increase understanding about deeper technical and design issues. As opportunities for optimum application of SES are typically either lost or found in the earliest design stages of a project this tool has the potential of increasing consideration and uptake of SES.

7 REFERENCES

- Anon. 2002, Directive 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, Official Journal of the European Communities, 4.1.2003
- Anon. 2004, Integrating renewable energy into new developments: Toolkit for planners, developers and consultants., Greater London Authority, UK, ISBN 1 85261 660 1

The Use of EPDs in Building Assessment - Towards the complete picture

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ABSTRACT: The environmental impacts of buildings occur throughout all life cycle phases. To overcome the shifting of burdens from one life cycle phase to another when deciding between options, the life cycle perspective needs to be regarded by the design and planning teams. An environmental assessment needs to be tailored to the unique building and carried out according to specific design and surrounding conditions. At the same time, the building assessment has to be applicable in practice.

Environmental product declarations (EPD) according to ISO 14025 provide comparable and reliable information on the environmental performance of products. They contain verified data of Life Cycle Assessments (LCA) of the product and are based on both, consistent background data and manufacturer specific data. Current developments in standardization of frameworks for sustainability building assessment systems build on the use of EPDs to cover environmental aspects of construction, e.g. as foreseen in CEN / TC 350.

1 INTRODUCTION

The environmental impacts of buildings occur throughout all life cycle phases: Starting with the production of the building materials, followed by the construction and operation and renovations of the building, until the final demolition and disposal of wastes. To overcome the shifting of burdens from one life cycle phase to another when deciding between options, the life cycle perspective needs to be regarded by the design and planning teams.

Hence, the overall environmental performance of a building can significantly be enhanced when it is designed regarding the life cycle perspective and the impacts of all building aspects. Green design provides uncountable numbers of options for the planners. But unlike to industrial products, each building design has its very specific requirements by the user, the owner, the building's local conditions and the design team. Therefore, an environmental assessment of a building needs to be tailored to the unique building and carried out according to the specific design and surrounding conditions. At the same time, the building assessment has to be applicable in practice and needs to fit to the workflow of the design team. The trade-off between accuracy in the analysis of the building and appropriateness of the involved effort is of crucial importance for efficient application of life cycle based environmental assessment.

Environmental product declarations (EPD) according to ISO 14025 provide comparable and reliable information on the environmental performance of products. They contain verified data of Life Cycle Assessments (LCA) of the product and are based on both, consistent background data and manufacturer specific data. Current developments in standardization of frameworks for sustainability building assessment systems build on the use of EPDs to cover environmental aspects of construction, e.g. as foreseen in CEN / TC 350.

This paper will introduce how to efficiently analyse the environmental life cycle performance of buildings. It will focus on current developments in generating EPDs and the future use of EPDs in building assessment.

2 ENVIRONMENTAL PRODUCT DECLARATIONS (EPD)

Environmental Product Declarations according to ISO 14025 (also known as ISO Type III labels) communicate product specific results from a Life Cycle Assessment according to ISO 14040 in a formalized and comparable way. Besides LCA results, EPDs declare other environmentally relevant issues, which are not covered by LCA, like technical data or information on special substances.

For the generation of EPDs, three different general steps can be distinguished. 1) The standard sets the framework for EPD programmes and the validation of EPDs. 2) Within the EPD programmes, detailed rules for the LCA of defined product categories are elaborated by the programme holder: "Product category rules" (PCR documents). This encloses the requirements for additional information. 3) According to these rules, the data for the EPD for the respective product category is gathered and documented.

An Environmental Declaration Programme provides both general and product category-specific prescriptions for data collection, handling and calculation rules. In the product category rules (PCR) i.e., a set of specific rules, requirements, and guidelines for developing Type III environmental declarations for one or more product categories are contained. A multi-stakeholder open consultation process approves the PCRs. General idea behind EPDs is not to give criteria for assessment, preference or minimum levels to be met, but to provide information on which the customer can compare products by comparing the quantified results.

EPD programmes can be found in several European countries, many of them specialized for the building sector. Environmental product declarations are a very young communication tool and quite obviously their diffusion by companies is fairly limited in absolute numbers. In Germany, the only type III EPD program is for building products. It was developed in 2004 by AUB (Association of Building Product Producers and Distributors / Arbeitsgemeinschaft Umweltverträgliches Bauprodukt e.V., see www.bau-umwelt.de). One of the most important applications of EPDs in the building and construction sector is the use for the environmental assessment of buildings.

As programme holder, the AUB organizes all steps which are required for the EPD generation. Up to now 14 PCRs for different construction products are developed. PCRs are verified by the independent advisory board, EPDs are verified by verifiers authorized by the independent advisory board, a certification is not requested. The AUB program is supported by several governmental organisations, like the Federal Ministry for Transport and Construction (BMVBS), the German EPA (UBA), the German Institute for Building Technology (DIBt) and the Federal Institute for Materials Research and Testing (BAM).

Content and environmental indicators in an AUB-EPD

EPDs according to the AUB system contain the following chapters:

Summary

0. Product definition
1. Raw materials
2. Manufacturing of the building product
3. Working with the building product
4. Building product in use
5. Singular effects
6. End of life phase
7. Life cycle assessment
8. Evidence and verification
9. References

The summary of the EPD (1 page) contains the results of the life cycle assessment (LCA) conducted according to the ISO 14040 series. A tabular overview, as defined in the AUB framework for EPDs, provides information on the following environmental indicators (see figure 1):

1. Primary energy, non-renewable
2. Primary energy, renewable
3. Global Warming Potential (GWP)
4. Ozone Depletion Potential (ODP)
5. Acidification Potential (AP)
6. Eutrophication Potential (EP)
7. Photochemical Ozone Creation Potential (POCP)

Titanium zinc sheet				
Parameter	**Unit per kg**	**Sum of production and recycling potential**	**Production**	**Recycling potential**
Primary energy, non-renewable	[MJ]	**16.3**	45.5	- 29.2
Primary energy, renewable	[MJ]	**0.9**	3.8	- 2.9
Global Warming Potential (GWP)	[kg CO_2 eqv.]	**0.96**	2.62	- 1.65
Ozone Depletion Potential (ODP)	[kg R11 eqv.]	**$0.18 * 10^{-6}$**	$0.56 * 10^{-6}$	$- 0.39 * 10^{-6}$
Acidification Potential (AP)	[kg SO_2 eqv.]	**$3.32 * 10^{-3}$**	$13.5 * 10^{-3}$	$- 10.2 * 10^{-3}$
Eutrophication Potential (EP)	[kg PO_4 eqv.]	**$0.28 * 10^{-3}$**	$1.03 * 10^{-3}$	$- 0.76 * 10^{-3}$
Photochemical Ozone Creation Potential (POCP)	[kg ethene eqv.]	**$0.29 * 10^{-3}$**	$1.10 * 10^{-3}$	$- 0.80 * 10^{-3}$

Figure 1: Environmental indicators in an AUB EPD on the example of a titanium zinc sheet

3 ASSESSMENT AND CERTIFICATION OF THE SUSTAINABILITY OF BUILDINGS

Background

Being amongst the most active industries, the building industry significantly characterizes a country’s overall appearance. It also draws upon major parts of the country’s energy and resource demands to construct, maintain and use the built environment. Forward-looking actors in the industry’s value-chain show rising consideration for the concept of sustainable building and construction. This is mainly driven by a grown awareness to environmental issues like climate change and resource depletion, rising requirements of investors and building occupants to health & comfort aspects and economic efficiency goals in the construction / use phase of a building.

Designing and constructing tomorrow’s buildings bears a high social and environmental responsibility. Today’s challenge for architects and planners, investors and operators, building material producers and building contractors means sustainable and efficient building and construction. Sustainable building and construction considers social, economic and environmental aspects of producing, operating and demolition of the built environment. Because all buildings are unique objects, a sustainability evaluation on the building level is prerequisite. The instrument “Certificate of the sustainability of buildings” serves this purpose.

The German expert panel “Round Table for Sustainable Construction” is currently providing indicators and discusses quantification issues to reach a consensus. It consults the ministry in improving guidelines and bringing these into practical use. The German Sustainable Building Council will accept the challenge of implementing these guidelines and further national and international agreements into practice.

The Sustainability Certification System of the German Sustainable Building Council (GeSBC)

The German Sustainable Building Council (GeSBC), which is currently being established, intends to fostering and implementing sustainable building and construction through its members. The aim of the association is to provide a certification system for buildings to provide a certificate on the sustainability of a building for investors, owners and occupants. The certificate is in line with the international standards for sustainability assessment of buildings under development e.g. as foreseen in CEN / TC 350.

The application of the system, which is currently being tested in its preliminary version, is tailored to the high quality German requirements but will be also applicable in an international context. This is due to the fact that German building techniques and solutions to support sustainability have a very good repetition in other countries. One of the main principles of the certification system is to provide a systemic view on the entire building and to integrate the life cycle perspective adequately. This allows fair evaluation of building elements within the building.

The GeSBC building assessment system follows the principles:

1. **Sequential certification**: The building assessment starts with setting individual objectives and results in a certificate of the approval of these objectives. The assessment fits with the workflow of the planner, which includes a balanced demand for and provision of information at the right points of time in the planning procedure.
2. **Design flexibility**: The application of the assessment system does not hinder architects and planners in their design flexibility.
3. **System view and life cycle perspective**: The big picture view on the entire building is basis for efficient sustainable construction. The life cycle perspective prevents shift of burdens. EPDs are regarded as one important communication instrument for the system.
4. **Individual references and focal areas**: The assessment reference draws back the local references and surrounding conditions. Focal points are determined individually, baseline quality requirements ensure a high overarching quality level.

As a general rule, the GeSBC certification system will base its life cycle related information on EPDs. Considering the life cycle perspective is amongst the main principles of the system. The concept of sustainability is accordingly translated to the building sector and is addressed in the GeSBC certification system in five categories:

1. Economic aspects
2. Protection of resources (input side of environmental aspects: depletion / landuse)
3. Protection of nature (impacts on the natural environment)
4. Health and comfort (impacts on the user of the building)
5. Societal aspects and surrounding

Result of the assessment will be a certificate, differentiated into five stars (gold or silver level), according to the areas of protection. Basic requirements on the entire quality of the building have to be fulfilled in any case. To come to a result for each area of protection, even if an indicator is today not quantifiable (e.g. simulation of VOC concentration in a room of a building based on emission rates of the building products), the aspects can be aggregated to the result. But it is always the goal to do the quantification on the indicator level.

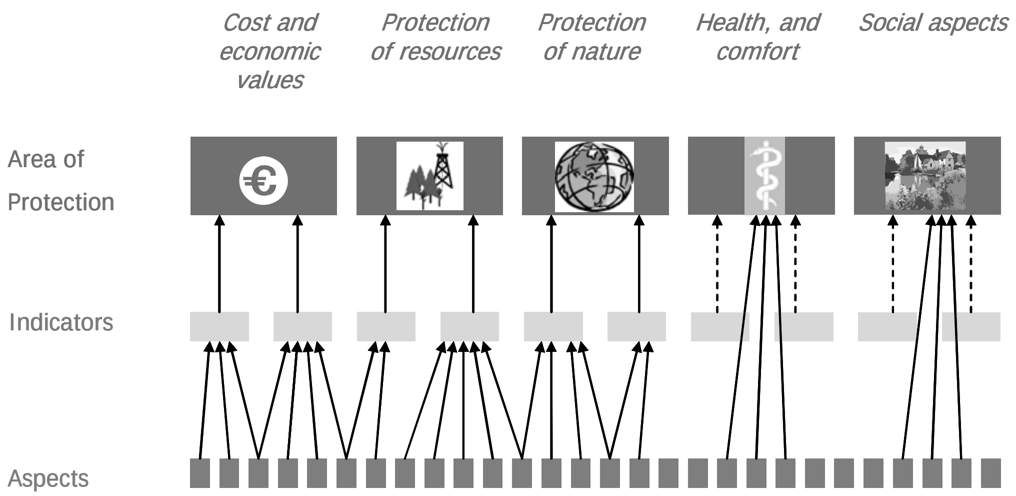

Figure 2: Overview on the assessment scheme: Differentiation into building aspects, indicators and areas of protection

The life cycle perspective will be addressed in the certification system for the economic aspects by considering the life cycle costs of the building and for the environmental aspects by applying life cycle models which give quantified results for the environmental aspects protection of resources and nature.

4 THE USE OF ENVIRONMENTAL PRODUCT DECLARATIONS IN THE GESBC CERTIFICATION SYSTEM

Within the GeSBC sustainability assessment system and in accordance to the upcoming international standards, it is foreseen to integrate EPD information on different levels:

1. Big picture view on the entire building over its life cycle: Background information for a “model specification LCA”
2. Quantification of the sustainability performance of specific building aspects in detailed assessments

Information transfer from EPDs to the assessment system

The environmental indicators provided in EPDs from the AUB system match perfectly with the environmental information needed on indicator level for the “Protection of resources” and “Protection of nature” areas of sustainability in the building assessment system of the GeSBC. Figure 3 represents this matching of currently available information from product specific EPDs or EPD-based databases on construction materials.

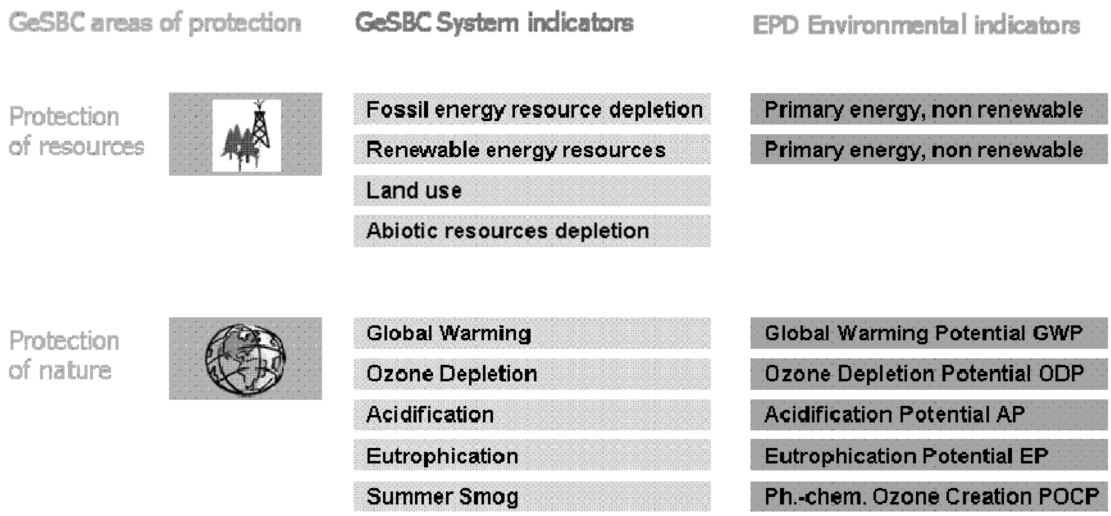

Figure 3: Environmental indicators in the GeSBC assessment system and provided in EPDs from the AUB system

Currently no sufficiently proven scientific sound and applicable methods exist for land use and abiotic resource depletion which allow integrating quantifiable information into either of the systems. Currently, effort is undertaken to provide methods and data for both indicators and it is expected that in the next year, quantifiable data for an assessment is available.

Application of EPD-based information within the GeSBC system

1. Background information for building LCAs

Ending this year, initiated by the German Federal Ministry for Transport and Construction, a project is ongoing which aims at building up an LCA database for building materials. This database delivers average datasets on materials and building elements, provided and reviewed by manufacturer associations. This data is suitable for environmental life cycle assessments in early project phases, where manufacturer-specific information is not available or known. The aggregated information represents the planner’s knowledge at that planning point of time.

The information of the EPD-based database on average product level will be the underlying environmental information for the life cycle assessment of the entire building. It will be used to provide the big picture view on the entire building. This helps focusing on the relevant parts of the building’s life cycle.

In practice, two general approaches will be followed when carrying out LCA studies for an entire building for the aforementioned purpose. One will be to specify a pre-defined life cycle model of a building by entering easily available technical information on the building. This kind of study will be based on a “building model specification LCA”. This model already exist for the building type “residential housing” and will be adapted for further building types in near future.

The second approach will be a (eventually web-based) modular approach, which allows combining LCAs of construction elements, building services, room specification, exteriors, etc. to a complete building LCA. In this “modular building LCA” approach, the level of detail can vary between the different modules according to the (environmental) relevance and available information.

Both approaches, the building model specification LCA and the modular building LCA, will be based on the same LCA database for building materials. As explained before, this database will contain EPD-based aggregated LCA information.

2. Building product specific LCA information

The second area of applying EPDs in the building assessment system is for environmental evaluation on product level. In an advanced planning point of time, product specific EPDs provide verified and quantified information on indicator level, which allow an unbiased environmental evaluation. Using LCA information on indicator level prevent from getting assessment results on unjustified - because building and situation independent - pre-rated information.

When assessing e.g. different flooring products, average information is not sufficient from the occupant’s point of view for all aspects. The occupant is interested in the calculation results of the specific flooring within the specific building and situation. Additional product specific relevant information, e.g. VOC emission values for flooring products, are part of chapter 8 of an AUB EPD “Evidence and verifications”.

This product specific assessment allows referring environmental effects and benefits to the products under consideration. This supports the manufacturers’ efforts to provide exact information and allows tracing and displaying product improvements.

5 CONCLUSIONS AND OUTLOOK

A fair and unbiased sustainability building assessment requires verified and quantified information about environmental aspects of the building’s elements. The life cycle perspective avoids shifting of burdens and is widely considered being the main principle of sustainability assessments. This is reflected in the ongoing international standardization activities on sustainability assessment of buildings.

The sustainability assessment system of the GeSBC incorporates the German LCA database for construction materials and manufacturer specific EPDs. This integrative approach ensures consistency of the underlying environmental information and the exact matching of provided indicators for the sustainability assessment.

The system will be in line with the upcoming international standards on sustainability assessment. Verified Environmental Product Declarations play a crucial role in granting a fair and unbiased assessment system.

6 REFERENCES

P. Frankl, P. Fullana, J. Kreißig, 2007: Communication of Life Cycle Information in the Building and Energy Sectors, Draft version of the report from the Task Force on Communication of Life Cycle Information of the UNEP/SETAC Life Cycle Initiative, February 2007

BMVBS, 2001: Guideline for Sustainable Building. German Federal Ministry for Transport, Building and Urban Affairs, Berlin 2001

Working documents of CEN TC 350: ‘Sustainability of construction works–Framework for assessment of buildings‘

Working documents of ISO DIS 21930: Building construction - Sustainability in building construction. – Environmental declaration of building products

Some observation about the efficiency of building sustainability assessment tools

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ABSTRACT: This paper introduces an analysis about existing building sustainability assessment tools. This analysis is based on five criteria that would detect how efficiently the tool can help to achieve sustainable buildings.

INTRODUCTION

In our research existing indicator tools have been analysed and an important issue has been detected: How efficiently does the tool achieve sustainability?

We call efficiency the relation between the quality of the assessment and the effort necessary to create and proceed the information for the evaluation.

We consider that building's sustainability assessment tools need a standard to question their efficiency. The consequence is that sometimes they are too expensive, complicated to use, and far from their initial function: to inform about the sustainability level of the building and, more globally, helping to make the buildings more sustainable.

The reflections of this document arose in order to answer to the questions of the authors collaborating with the Verde Tool, managed by the GBC Spanish team. The results of this cooperation have been presented in 2005 in Tokyo, during the Sustainability Building Congress SB05. Many of the questions expressed in this document have been reported during the Congress, where we tried to give clear answers, adapted to the particular conditions of Spain.

In this paper we propose five criteria which take in consideration efficiency aspects. These aspects, in our opinion, should be fulfilled by the sustainability assessment tools in order to ensure their quality, their usability, their economy and their utility to orient the user toward sustainability.

These criteria are:

1) The score as reflection of sustainability;

2) Economic viability of use;

3) The profile of the user and the ambit of application of the tool should be clearly established.

4) The tool should be given possibilities of change. It should suggest sustainable actions, each evaluation step should be possible to trace and the proposed project changes should be economically viable.

5) To be a Complete Model with the Minimum Number of indicators

In this paper the five criteria are applied to important indicator tools as Casbee, Gbtool, Itaca, Leed.

1.1 *The score as reflection of sustainability*

At the level of tool this criteria points out what the final score say us…the level of sustainability of the building or something different? At level of the single indicator, the criteria point out how correctly the evaluation is.

The OECD (1993) asks that an indicator gives a representative image of environment conditions and the pressure to the environment. We consider that the main objective of a building sustainability assessment tool is to give an idea of the level of sustainability of a building. For this reason, we consider we have to avoid previous or foreign evaluation factors as, for example, comfort conditions, factors which have to be established before in the project, and be useful for the definition of the resources that we need to obtain these conditions.

Certain complexity appears in the discussion because there is more than one definition of sustainability or more than one way to evaluate it, in different ambits. It could become even more complicated when we have to define the limits of what we want to measure, whatever is the ensemble of buildings we investigate.

We consider that while the smallest is the ambit of application (it could be ambit of: typology, use or geography), more valid is the tool evaluation. If we would work with geographical ambits (none of the tools really define and limit geographical ambit for its application) the building systems, the climatic conditions, the possible project alternatives, would be more realistic.

In the evaluation of the single indicator it is important that the ranking change proportionally to the sustainable benefit. It would be possible to meet these errors that can generate wrong evaluations:

1- Little efforts to improve the project could cause noticeable changes in the evaluation.

2- Major efforts to improve the project could cause little changes in the evaluation, because of the quality of the information or its elaboration.

3- The difference between the ranking value is not environmentally important. Or it would depend on uncontrollable factors. The difference between the ranking values would say how and how much we can improve the project.

For example, the score given by Casbee does not include exclusively the environmental performance of the building but it depends on other factors less relevant for the sustainability. Casbee value: Building Environmental Efficiency = Building Environmental Quality & Performance / Reduction of Building Environmental Loading. This means that the environmental efficiency is considered directly proportional to the interior quality of the building, often get with a high energy cost.

This kind of evaluation doesn't give a limit to the outgoing resources and can evaluate as Environmental Efficient a building with a good comfort level, but with a large use of energy, material resource and water. And, on the contrary, evaluated as reduced Environmental Efficiency a building that respect the comfort standard and have a normal use of "Water resources, Materials of low environmental load, Natural Energy".

An unlimited improvement of comfort would be justify, with relative improvement of outgoing resources, when the sustainability asks for the decrease of them.

We will give more importance to the sustainability factors as Water resources, Materials of low environmental load, Natural Energy Utilisation of section Reduction of Building Environmental Loading.

Itaca includes seven sections, but only four are concerned, relatively directly, to the sustainability: Transport, Resource Consumption, Exterior Ambient Quality, Environmental Loading. The other three sections are Interior Ambient Quality, Quality Of Service, Management Quality. They are related less directly with the sustainability. They include very important factors in a building project but not to assess its sustainability. Itaca touches severals aspects, as electromagnetism, acoustic comfort, and so on, which are very important for the comfort and wellness of building user, but not directly connected with sustainability.

In Leed we find five items: Sustainable Sites, Water efficiency, Energy & Atmosphere, Materials & Resource, Innovation & Design Process*,* directly concerning the sustainability. Plus Indoor Environmental Quality that is not directly connected with sustainability. As a consequence the evaluation given by Leed will reflect the effort made for the environmental sustainability of the building.

1.2 *Economic viability of use*

This criteria would evaluate if the use of the tool is sufficiently inexpensive. The indicators will be measurable at reasonable cost. Moreover for this aspect it would be necessary to ask for every indicator to be clear in content: easily understandable, with units that make sense, expressed in imaginable, figures.

Buildings are complex systems. In order to make a model that would include all implied factors it is a complex and time consuming work. We need a lot of information for it. Reasonable cost is an important issue. Our proposal to simplify the collection of all needful information is that the tool would demand to the already available information of the project. Even more possible, the information would be expressly enunciated in the project. The cost to elaborate more information for the assessment is very high (it is the problem of various existing tools).

The indirect measure of the building characteristics to simplify and reduce the cost of dates collection would be risky for the evaluation quality. It would be worse if the geographic range is large. The value would be defined at a reasonable cost. The effort to use the tool could be acceptable in relation to its utility. The cost to collect the dates would be proportional to the weight of indicators in the tool.

For example, in Casbee, the indicator "Q-1, 1.1–*Evaluate the level of indoor background noise produced by air conditioning and by external traffic noise (Db)*" needs a complex and unusual calculation in a project (at least in Spain). In GBTool we meet positive example when it asks dates that we can meet in the project. In the section Architectural Systems: "AR6 - *Site area hard-paved, non-permeable* (m²)", OR "*Site area landscaped with species not requiring watering* (m²)", OR "*The volume of solid wastes resulting from the clearance of existing structures on the site that will not be sent to a solid waste facility* (%), *aggregate not in concrete* (*density in kg per m3 area*)", and so far. They are all indicators that demand dates that we can meet in the project, easily understandable, and as a consequence, limiting effort, economic investment and giving to the tool more possibility of success.

1.3 *The profile of the user and the ambit of application of the tool should be clearly established.*

This criteria searches if the information could be transmitted adequately to the user –for that reason it is necessary that the user profile must be clear, and the objet application were well defined.

It is necessary to foresee who the tool user is. We consider the user would not be a specialised technical in the tool use, not implied in the project, generally. If we want that the tool will be really useful the user would be a professional imply in the project, and using more times the tool, he will know what are the changes to have a more sustainable building.

It would be useful to foresee that the tool could have various kind of users. The evaluation could certify to the user that the building where he lives has defined environmental characteristics. The promoter could use the tool to establish what are the necessary actions, and the relative costs, to have the desired environmental quality. The architect could use the tool to verify the environmental efficiency of the last version of the project.

The ambit of application could be the Design Stage or the Use Stage. In the Use Stage the tool would evaluate a finished and no alterable product. If the idea of the tool were a guide to favour the building sustainability, it has to propose corrective actions, and the relative costs, in the project stage, when it is still possible to modify project decisions.

In this way, Leed address to a technical person, it communicates with physical units, of materials to use, action to do. Leed not even asks what are the building CO2 emissions, something unusual for the technical of building sector. It just propose actions to limit the energy consumption and the use of high emission resources, it aims at avoid the cause more that reduce the effect. For example in the section Materials & Resources it asks: *"a minimum of 20% of building materials that are manufactured regionally within a radius of 500 miles"*, OR in the section Energy &Atmosphere it asks "*Supply a net fraction of the building's total energy use (as expressed as a fraction of annual energy cost) through use of on-site renewable energy systems"*.

1.4 *The tool should be given possibilities of change. It should suggest sustainable actions, each evaluation step should be possible to trace and the proposed project changes should be economically viable.*

This criteria demands that the tool gives and implements to the user to change the project and improve its sustainability. It could depend on:

1 If every step of the evaluation is traceable;
2 If the tool suggest sustainable actions of change
3 If these actions have a reasonable cost.

We consider that the purpose of these tools it's not just the evaluation of environmental quality but to communicate it to the tool user. It is to give to the technical people the information that can impact their decisions, to influence the building sector and improve its sustainability. The purpose of this kind of tool would be to help the project decision process in the project stage to realise more sustainable constructions. The tool would be directed to a technical on building sector. In order to make more sustainable project, in state of a technical of the tool whose purpose could be just to assign a score.

_For example in Casbee, these indicators suggest actions: *LR3-3 Wind Damage & Sunlight obstruction* and gives a table that associates the evaluation with the quantity of effort and accomplished actions. It value using dates found in the project. *LR1-2 Natural energy utilisation*: this indicator proposes actions to goad the use of natural energies.

Leed indicators give to the user relevant information, that can influence his decisions.

Example of the above are in the section Materials & Resources: "*Building Reuse - Maintain 100% of existing building structure and shell AND 50% non-shell (walls, floor coverings, and ceiling systems)"; "Construction Waste Management - Recycle and/or salvage at least 50% (by weight) of construction, demolition, and land clearing waste"*. These indicators respect also the third point of this criteria (to propose actions with a reasonable cost), because the proposed actions have a reasonable cost, they are solutions that we can meet frequently in the building market.

What we don't find in any tool, is the relation benefit/cost of proposed actions. It has no sense an evaluation based only in theoretical possibilities without the consideration of the necessary economic investment. It would be very useful that the tool considers that we produce the investment in the more efficient way (The promoter asks: "how can I invest the first economical resources to obtain the best environmental improvement?". The user asks: "How much money did they spend to improve the building sustainability?").

The cost of the evaluation of a project is not just to evaluate it not only the first time, but it is the effort to identify change options, and – and this is very important - to evaluate the benefit and the cost of every one of them. In relation to ranking definition would exist the possibility to apply new techniques existing in the market, that could give best results. It would exist the possibility to include also its cost.

1.5 *To be a complete model with the minimum number of indicators*

This criteria asks that the tool is complete, that it touches all the important items, but that the quantity of the indicators should be as limited as possible. It asks that repeated or unnecessary indicators were no present.

We consider that in order to generate a complete model of the building we have to take in consideration all the flows –fuel, raw materials, water, and of course the soil- crossing the building in its life cycle: project stage, building stage and production of building materials, using and upkeep stage, demolition.

It is very important that the quantity of indicators would be limited and all that would be necessary. The tool will be composed only by the essential indicators, so its would be more comfortable and with an high throughput, to avoid contradictions or to take in consideration the same factor more than ones.

In this sense, a lot of tools don't take in consideration, for example, that the environmental loading are a consequence of resources consumption: after the use of the resources what remain are residue. The environmental loading are that waste disperse in the environment (air, water, soil). It is necessary avoid to consider two time the same factor, it is necessary avoid to consider both resource consumption and environmental loading.

CONCLUSION

As a conclusion, we present the proposal that a solvent institution - maybe iiSBE– could begin to think as an aim at the definition of efficiency criteria for the building sustainability assessment tools, and not only about their quality.

The proposed criteria – or the ones that could arise with an ample argument–would be applied to existing tools, as in this document we have tried to achieve as an example, with some of the more well-known and prestigious existing tools. Also some standards could be elaborated to ensure the efficiency in the building sustainability assessment.

Beyond of the paper aims – although very connected to them – we can find arguments about central factors in the building sustainability evaluation, as the sustainability concept that we also find behind every tool. We propose ethical use of the building, the concept of sustainability should be enunciated in every tool. so we very much hope that the finished building would never be used as torture centre or made with slave or children's labour, even if have obtained a good score.

REFERENCES

Green Building Challenge (GBC) 2002. *GBTool*. http://www.greenbuilding.ca/down/gbc2002

Gruppo di lavoro interregionale in materia di bioedilizia 2004. *ITACA*. http://www.itaca.org.

***U.S. Green Building Council. June 2001.* LEED version 2.0*. http://www.usgbc.org*.**

Institute for building Environment and Energy Conservation (IBEC). 2003. CASBEE.

Cuchí Albert. Castelló Daniel, Díez Glòria, Sagrera Albert, 2003, *Paràmetres de sostenibilitat*. Barcelona: IteC-Institut de la Construcció de Catalunya.

Cuchí Alberto, 2004, *Document for the elaboration of Verde - the building sustainability assessment tool for Spain*, No published, Barcelona.

Cuchí Alberto. 2006. *Les restriccions en la mesura de la sostenibilitat. Un cas d'applicacio*. Barcelona: I International Conferenze on Sustainibility Measurement and Modelling ICSMM 06.

Meadows Donella. September 1999 *Indicators and information Systems for sustainable Development – a report to the Balaton group.* The Sustainability Institute.

Bossel Hartmut. *Indicators for sustainable development: Theory, Method, Applications - a report to the Balaton group.* IISD-International Institute for Sustainable Development.

OECD. 2000. *Towards Sustainable Development – Indicators to measure progress.* OECD

ISO. 2004. *CD 21929 Building construction – Sustainability in building construction – Sustainability Indicators:* ISO.

ISO. 2004. *CD 21931 Building construction – Sustainability in building construction – Framework for assessment of environmental performance of building*

Vitória's healthcare buildings environmental performance based on LEED-NC 2.2

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ABSTRACT: This paper represents the sustainability and environmental responsibilities for healthcare buildings. To accomplish the goal of this research, it has been done a simulation of the LEED methodology in three different healthcare centers and had been based on the existing blue prints and interviews with people fully involved in the whole process, from the beginning on elaboration of the program requirement list of the building, the concept, design and execution. The methodology applied was based on the concept of sustainability and discussed about subjects such as, water, indoor air quality, thermal comfort, landscaping, renewable energy, VOC's, with main goal to evaluate the environmental perception and sensibility of personnel involved, making a connection between the score and the project. Showing first, the poor knowledge of the subject. The casual score was only in the indoor air quality and sustainable sites, missing the green thinking. Just the basic legislations were applied.

1 INTRODUCTION

1.1 *Contextualization*

The sector of civil construction is known as one of the most accountable for the environmental impacts in Brazil and in the world. From the great amount of natural resources used in all of its production processes, the project design concerning aesthetics only and the bad choices regarding materials and environmental comfort concepts to the great amount of waste due to handicraft construction techniques used by unqualified labor (SILVA *et al*., 2000).

As part of the strategies to fulfill the local environmental goals established in ECO 92[1], methodologies for buildings environmental performance evaluation arose both in Europe and North America. These methods had in common the main objective of stimulating the market demand for higher levels of environmental performance and focused exclusively on the environmental dimension of sustainability, although the range of civil construction is wider, and consequently with a greater need for re-evaluation in all of its aspects, including economic and cultural, for sustainability is also based on social action and for all that it stands for: shelter, health and social interaction (COOK, 2001).

The discussion of environmental impacts created by civil construction still requires deepening and specificity, as it is necessary to consider that different scopes are required for certain building typologies, according to its nature of use. Particularly, buildings housing healthcare services put higher pressure on the environment, because of their high water and energy use, which are indispensable for maintaining asepsis level, and because of the several pieces of equipment, essential to the core activity, 24 hours a day, 365 days a year. Therefore, conflicts between biosafety and water and energy saving may occur from any analysis.

[1]. United Nations Conference for Environment and Development, occurred in 1992 in the city of Rio de Janeiro, Brasil.

Up to these days one can observe that buildings are constructed with potentially carcinogenic materials such as wood composites, which use glue for pressed wood of formaldehyde-base[2]. These spaces must stimulate the use of products free of persistent bio-accumulative toxins, of chemicals and heavy metals such as mercury, lead and chromium, and especially free of PVC materials which are the largest cause of dioxins, the most dangerous substance ever produced by man. Construction management of healthcare buildings must know more sustainable construction techniques, ensuring the existence of healthier environments for all (GGHC, 2004).

1.2 *Evaluation methods for environmental performance*

Practically every country in Europe, Asia, besides the USA and Canada, have their own evaluation methods for environmental performance, and according to CIB[3] (2000) their focuses are diversified according to each country's reality and to its respective lacks and abundances of natural resources, climate factors and others.

Yokoo (2005) highlights the main initiatives among the existing environmental performance evaluation systems, namely: BREEAM - Building Establishment Environmental Assessment Method; CASBEE- Comprehensive Assessment System for Building Environmental Efficiency; GBC - Green Building Challenge; LEED- Leadership in Energy and Environmental Design.

Such publications are systemic environmental evaluation tools, internationally acknowledged, in some cases searching for a worldwide application of the methods.

In the present paper LEED methodology will be used in order to evaluate healthcare stations in the city of Vitória. The authors' choice for LEED was based on the fact that it is one of the most popular evaluation tools worldwide, and it has a simplified structure, assessing the sustainability of the whole building performance. Based on well-founded scientific standards, LEED method emphasizes strategies for the local sustainable development, water saving, energy efficiency, material selection and indoor air quality (USGBC, 2007).

Comprising a checklist that attributes credits to the fulfillment of pre-established criteria, each criterion is divided into credits that are basically project, construction or management actions that contribute to the reduction of the environmental impacts of the buildings. LEED results from a balance between prescriptive credits and performance specification, having as preference the environmental principles by norms and recommendations by accredited institutions, and promotes the evaluation of the 'green' building by a 4 level certificate (USGBC, 2007).

1.3 *The municipalization concept and the healthcare stations in the city of Vitória*

Starting from the premise that a man lives in the town, actions were set for the primary health care, of municipal obligation. Inspired by the Alma Ata4 Conference, these actions contemplate education, nutrition, family care, immunization, sanitation, endemic disease control, treatment of common diseases, and essential medication supply (GÓES, 2006).

Today in Brazil there are 3 categories of health care: primary, secondary[5] and tertiary[6]. On the primary level of health care the actions developed are health promotion, protection and recovery at an ambulatory level, sanitation and simple diagnosis. These activities are performed by auxiliary, technical, including doctors, nurses and dentists. The physical structure for this primary health care is the health centers, projected for populations between 500 to 2,000 inhabitants (GÓES, 2006).

Of the 170 million people in Brazil, 71.20% have a regular health care assistance. More than 30 million Brazilians have never gone to a dentist. A large part of Brazilian population is assisted by the health care stations on regular basis, which represent 41.80% of the procedures.

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[2] Formaldehyde is a colorless gas generally used in water solution as a preservative and disinfectant. It may cause cancer in significant concentrations.

[3] CIB-International Council for Research in Innovation in Building and Construction

[4] International Conference on Primary Health Care, in 1978 in the city of Alma ATA (USSR)

[5] The secondary health care level develops support to the primary level. It comprises ambulatory assistance and medical clinic, surgery, pediatrics, gynecology and obstetrics.

[6] The tertiary health care treats more complex system cases.

Only 21.50% enter the system through hospitals, 19.70% are treated in a doctor's office and 8.30% in clinics. (DATASUS, 2002 apud KASTRUP, 2006)

The information that around 47 million people enter the health care system in Brazil through the health care stations shows their value to the population in general.

The city of Vitória, capital of the Espírito Santo State, is the largest island of a group of 33 islands archipelago, and it is located on the southeastern region of Brazil, latitude 20º19'09" south and longitude 40º20'50" east of Greenwich. (PMV, 2007).

The health care system of Vitória's municipality comprises 28 basic units which provide medical and nursing assistance, psychological, social and dental care, blood pressure monitoring, curatives, exam collection, nebulization, shots, vaccines, providing medication assistance groups to several programs, and referencing for reference centers[7] (PMV, 2007).

Despite the fact of being considered one of the capitals of the country with highest life quality level, from the public health point-of-view the state capital was recognized by the Social Development Ministry which ranked it in the top-12 of 400 cities regarding health care (PMV, 2007).

These data stimulate the authors to invest in the search for improvement in the health care system once the quality of the facilities is part of this process according to Foucault (1990) apud Toledo (2006: p.17) who said: "[…] From the moment that the hospital is conceived as an instrument for healing, the architecture and the distribution of space become a therapeutic instrument […]".

2 OBJECTIVES

The objective of this article is to evaluate, based on the criteria established by the LEED-NC 2.2 methodology, the environmental perception and the familiarity of the agents involved in all stages of the construction of health care stations in Vitória with the issue of environmental performance, including the elaboration of the needs program, projects elaboration and proposed building execution and, yet, if there is concern about the benefits and harms that the constructed environment can bring/cause, perceiving to what extent the environmental performance subject is considered in the professional activities of doctors and designers involved in the process.

3 METHODOLOGY

Based on its objectives this research is characterized as descriptive accordingly to Gil (1996). All the architecture and engineering projects of 3 Health Care Units were analyzed based on the LEED-NC 2.2 methodology, with visits to the construction sites to assess the fidelity in project execution. From the technical procedures or research strategies point-of-view it assumes characteristics of survey and case study.

Regarding the data collection instrument, still accordingly to Gil (1996), semi-structured interviews with the main agents involved in the construction of health care units in Vitória were carried out, aiming to complement the information gathered from projects and from the study of the interviewees' perception of the main subject of this research, obtaining qualitative results, while when the methodology LEED is applied, the results are quantitative.

3.1 *Criteria used for the selection of analyzed works*

The paper analyzes 3 municipal health care units: Praia do Canto, Santo André and Jesus de Nazaré Units. The criteria for selection was defined by the social-economical diversity of the communities where the units were implemented, the different types of vertical circulation, the different architects responsible for the projects and the date the construction was finished.

[7] Secondary health care level structure.

3.2 *Criteria used for interviews*

Eighteen people were interviewed: 5 architects (1 project coordinator), 6 engineers responsible for complementary projects, 2 engineers responsible for carrying out the works, 3 doctors and 2 health care station coordinators. The same questions sequence was maintained for all interviewees, with some open questions that allowed the deepening in some aspects considered relevant, and the interview script was previously set and questions prepared in a way that the main subjects evaluated by LEED were approached and the objective achieved.

Questions were grouped, but the interviewee had no knowledge of such separation of subjects. Initially, a profile of the professional was drawn: name; graduation; professional experience; main area of work area; if he/she had a specific formation on health area; how the subject hospital architecture was approached during his/her university studies. The knowledge on norms relative to the studied edifications typology, form of contract and even the personal satisfaction with the building final result were also approached. The questions and their objectives were the same for all people interviewed and were grouped in blocks that are presented with their respective objects.

Block 1 – Legislation involved and the command over the necessities program: the objective was to assess the interviewee's knowledge regarding legislation and regulating norms such as: ANVISA RDC-50/2002 resolution (BRASIL, 2002); Health State Office norms; municipal code of posture of works; Urban Director Plan; flow and hierarchy of medical services. That way perceiving during the interview the familiarity of the person and his/her capacity to interpret the needs program, adjusting it to the many norms pertinent to hospital buildings.

Block 2 – Correlation between architecture with the health issue: the objective was to assess the interviewee's knowledge of the subject and if there is knowledge and sensibility to the benefits and harm that architecture and constructed environment can bring to health.

Block 3 – Environmental performance: the objective was to assess the interviewee's knowledge on the environmental impact of buildings and see to what extent the environmental performance subject is known and considered in his/her activity.

Questions were also made based on the criteria evaluated by LEED-NC 2.2 and grouped within each parameter analyzed:

Block 4 – Sustainable Site: the objective was to assess the interviewee's knowledge on the selection of the lot; correlation between the selected lot, the surroundings and the community; and available means of transportation

Block 5 – The water and its optimized usage: the objective was to assess the interviewee's knowledge on the problematic of the water issue and proposals for solutions of the building environmental impact on the subject.

Block 6 – Energy and atmosphere: the objective was to assess the interviewee's knowledge on energy efficiency; alternative sources of energy and ozone layer depletion. And to perceive the familiarity of the person interviewed with the proposed questions and the correlation made to seek the answers before the subject.

Block 7 – Materials and resources: the objective was to assess the interviewee's knowledge regarding concepts and definitions of issues such as products recycling; post- and pre-consumer; waste management; extraction and manufacturing of specified and used products.

Block 8 – Building indoor air quality: the objective was to assess the interviewee's knowledge regarding the materials toxicity and environmental comfort.

Block 9 – Innovations and Design Process: the objective was to perceive the interviewee's interest in research and propose innovations in the projects and work execution, and to assess the knowledge and level of professional update regarding new technologies applied on civil construction; ability to project when facing complex programs and to propose innovations and architectural solutions.

Block 10 – Satisfaction and results: the objective was to perceive the interviewee awareness regarding the final result, and what would the suggestions be within the subjects: form of hiring; contractor's interference; post-occupation evaluation; ranking of the final work results.

4 RESULTS ANALISYS

4.1 *Discussion regarding the knowledge and domain of Legislation and Necessities Program*

All the people interviewed demonstrated to know the legislations (despite not considering it clear and objective); however, the knowledge of the services hierarchy is unsatisfactory, with the need of always being revised by the project coordinators of the constructions municipal agency when the preliminary studies are delivered. The project designers do not receive a flow-chart of the services to be accomplished, and one architect said that in order to solve the program they consider a puzzle, it is enough to distribute everything along a corridor and you are complying with the norm. None of them said to have chosen to work in the health area but that the market had led them to the hospital buildings project for different reasons. Not one designer have any kind of specific complementary studies for this type of edifications.

4.2 *Discussion of the correlation between architecture and results in health*

Despite the fact that the people interviewed admitted a direct link between the constructed environment and the results in health, they said that the simple fulfillment of norms guarantees a healthy hospital building, "after all, norms exist for a reason. The consequences of the contact of some of the materials commonly used in the construction and the assembly of the constructed ambient have on human health are completely unknown and disregarded.

4.3 *Regarding the knowledge on the subject environment performance*

Environment performance, which is the central subject of this research, is not well understood by architects, doctors and health station coordinators, who confuse the term with environment comfort or even physical comfort. An architect said that his project contemplated environment comfort to the users because the room chairs were close to the office doors.

Following, the discussion will take place regarding each criteria analyzed by the LEED-NC version 2.2, citing the LEED-NC 2.2 manual credit (USSGBC, 2005) whenever necessary, to which the discussion refers to.

4.4 *Discussion of the results within the LEED methodology criteria*

4.4.1 *The environmental performance level of some edifications that house healthcare stations in Vitória according to LEED-NC 2.2 methodology*

The evaluation results of the 3 Health Care Units of Vitória are presented, accordingly to the criteria presented by the LEED-NC and Table 1 shows the summary of the results.

Table 1. Summary of the evaluation results of healthcare stations according to LEED-NC 2.2 criteria

LEED Criteria	Possible Points	Unit Praia do Canto	Unit Santo André	Unit Jesus de Nazaré
Sustainable sites	14	5 points	6 points	5 points
Rational Use of Water	5	0	0	0
Energy and Atmosphere	17	0	0	0
Materials and Resources	13	0	0	0
Indoor Air Quality	15	3 points	3 points	4 points
Innovations and Design Process	5	0	0	0
Points total	69	8 points	9 points	9 points

4.4.2 *The design process*

The SEMOB – Vitória Municipal Construction Agency maintains a project sector to carry out the city construction projects. However, this is not enough to meet the demands to prepare all the projects in the city, making it necessary to hire the services of other professionals in the city.

The services are hired through public biddings based on the necessities program established by SEMU – Municipal Health Office. The architect responsible for the project is also in charge of hiring the complementary and engineering projects, which he also coordinates.

The SEMOB project coordination team developed a book with specifications where finishing and other materials are standardized to all units. This book is supplied to the architect so that adaptations and adjustments to these standards, such as color, counter measurements, materials, etc. can be made depending on the project in development.

4.4.3 *Discussion regarding the sustainable sites criteria LEED-NC version 2.2*

In the stage of terrain or sustainable site selection, it can also be observed that scoring of points is present on the Public Transportation Access (SS credit 4.1), which is a determinant condition upon the site selection, since the public health service serves mid-low-class and low-class population, which need public transportation. It was noticed the lack of concern with stimulating the alternative transportation: parking spaces are small not to encourage the use of alternative transportation, but because the project designers were unable to carry out the program in smaller areas and leave part of the area for parking spaces (SS credit 4.4). Some of the interviewees related that fact with sadness, stating that they would like to have put one parking space for each professional that could afford a car. None of the constructions have bicycle storage. The permeability rate is always limited to the minimum levels and it was noticed in the interviews that the goal is only to comply with the obligatory urbanistic indexes and not a concern with soil absorption (SS credit 6.1). Any attempts to reduce the heat islands could not be verified in any of the projects (SS credit 7.1 e 7.2). Regarding the reduction of light pollution (SS credit 8) the scoring of points was due to savings in the execution stage and not because of the non-disturbance of the surroundings.

4.4.4 *Discussion regarding the LEED-NC version 2.2 rational use of water criterion*

None of the works scored points in the rational use of water criteria, irrigation and garden watering is done using potable water from the concessionary (WE credit 1.2.). Although part of the hired projects scopes, landscaping is always left aside or executed with plants from the municipal botanical garden, and not following the project. Pluvial waters is considered within hidrosanitary project traditional norms only for redirecting precipitation on the roof coverings, and its capture for reuse is not considered by project designers, who also did not foresee, even for future implementation, a treatment station for waste water (WE credit 3.2). Project designers argue that hydraulic equipment specifications come from the Construction Agency and there is a standard for all healthcare units. There is no cost benefit relation and it was noticed that most of the decisions are made based on the economical factor, aiming to costs reduction and savings in short-term. None of the people involved knows the average consumption of a healthcare unit, so that they are not concerned about using low-consumption equipment.

4.4.5 *Discussion regarding the LEED-NC version 2.2 Energy and Atmosphere criterion*

This criterion has not been addressed by any of the constructions, nor the pre-requisite have been complied with. It is not a common practice to have parallel teams to follow up projects in Brazil. The savings with energy is always seen as cost reduction in the maintenance phase and it is not related as in developed countries of cold weather whose energy comes from thermoelectric plants with effective atmospheric emissions, that is why the methodology puts so much emphasis on this phase and gives it a total of 17 points. The electrical project performed in the civil works of the Health Units is the most simple and basic possible. There are no three way switches, no presence sensor and no independent start (EA credit 1). The big energy problem in these buildings is related to the mechanical cooling and the choice of air-conditioners is done by the architect who already takes into consideration in the project where they are going top be installed. Currently the necessity program asks that all doctor's offices and administrative rooms are mechanically cooled excluding only the environments destined to support services. The most used systems id the Split, but they don not take into consideration if the cooling gas damages the ozone layer, as is the case of the CFC[8] still used by the majority of the producers (EA credit 4). Even in the Jesus de Nazaré Unit, which is located on the top of a hill and close to the sea and therefore, has excellent ventilation it was observed that the winds are kept constantly closed and the air conditioned is always on which characterizes the user lack of environmental

[8] CFCs or chlorofluorocarbons are the great responsible for 24% of the total global warming.

awareness. Most of the designers and doctors had difficulty mentioning alternative sources of energy and their production processes.

4.4.6 *Discussion regarding the LEED-NC version 2.2 Materials and Resources criterion*

The phase regarding the materials and resources used did not receive any points and the people in charge of carrying out the works admit that they did not select any residue generated in civil works for the selective garbage collection. None of the situations studied had any type of construction or fragment to be reused and even in the use phase there is no type of waste bin or container for selective collection of the garbage generated (MR pre-requisite 1), except for the hospital waste generated. The designers also don not know products which could have been used as construction materials which contain recycled raw-material from pre or post consumption of the products (MR credit 4.1 and 4.2) and, not even the term is known by some of the interviewees. The architects and contractors do not know the origin of the materials nor if the region where the construction is located there is a similar product (MR credit 5.1 and 5.2), most of the respondents did not understand the reason for the question and showed a complete lack of understanding that the warranty and maintenance of local jobs is connected with the problems generated by the traffic of trucks in a country where almost 100% of the transportation is done by roadways and consequently generates a depreciation of the road network and increases atmospheric emissions due to diesel combustion. They also could not mention any quickly renewable material which could be used in the constructions (MR credit 6) and they do not know where the certified wood can be found or bought (MR credit 7).

4.4.7 *Discussion regarding the LEED-NC version 2.2 Indoor Air Quality criterion*

The 2 pre-requisites were complied with. The IQ pre-requisite 1 is a mandatory part of the local construction code (minimum size of the ventilation ducts) and the second, although it is not included in the project the determination of places for smokers, but being the building a place for health services, it was automatically forbidden to smoke in the internal areas (IQ pre-requisite 2). There is no monitoring of the quality of the air entering and the ventilation ducts do not exceed the minimum required by the local regulation. During the construction phase none of the materials were protected to avoid dust or gas absorption (IQ credit 3.1). All the interviewees did not know what VOC and consequently it was not avoided the specification of high emission and toxicity (IQ credit 4.1, 4.2 e 4.4). After explaining the term and the main generation sources it was noticed that the doctors interviewed did not know the damages to health caused by formaldehyde, benzene, dioxins, etc. None of the projects have a control over the thermal conditioning and only the Santo André Unit had protection brises in the facade where the sun hits intensively (IQ credit 7.1). The care in the implementation to make the best use of the ventilation is neglected under the argument that the environments are climatized and the windows will be closed and thus there would be no need for ventilation, forgetting that the exchange of air is necessary to ensure hygiene and cleanliness, especially in places where it is common to have people contaminated with a variety of bacteria and viruses. In 2 units there were approximately 90% of the rooms using natural light and windows with a view to the outside (IQ credit 8.1 and 8.2).

4.4.8 *Discussion regarding the LEED-NC version 2.2 Technological Innovations criterion*

It was not possible to detect in the projects and it was confirmed by the interview that in none of the cases there was any innovation in the projects or the use of new technology as well as not used in the construction, thus there was no points for innovation in the project (ID credit 1-1.4).

4.5 *Discussion regarding the final results and satisfaction of the people involved*

To finalize, evaluated the satisfaction of the interviewees regarding the contracting and results obtained; it was verified that although all the interviewees classified the result positively the designers blamed the execution of the works for the existing flaws, while the constructors blame the contracting company and the financial limitations imposed to the construction. The contracting company explains that the contract follows bidding rules and do not allow for the selection of the contractors except for the lowest price. The evaluation of the interviewees was based on personal opinion as none of them followed up the execution of the works or carried out any type of post-occupation evaluation to check if the objectives were being complied with by the building. “If nobody complains we take for granted that it is working out the way it was done” said on of the coordinators of the project.

5 CONCLUSIONS

Observing the results from table 1, a similarity among the results of the three constructions assessed can be noticed, where the scoring of points concentrates on the phase of sustainable site and in the phase of indoor air. After analyzing the projects and the interviews, one can see that the level of the professionals involved in the project and construction of the buildings is very similar, therefore leading to the similarity in the results of the 3 constructions assessed.

The few points reached by the constructions analyzed are due to compliance with norms and not to environmental awareness, and concern with the building and its users. During the interviews it was observed a lack of knowledge regarding environmental issues. All of them were unanimous to say that the environmental targets would have been met if demanded, which shows a total disregard for environmental problems in general, being just worried with the compliance of norms.

It is believed that for a betterment in the performance of the future constructions of Health Units it would be necessary to carry out a reengineering of the whole process, from the elaboration of the needs program prepared by the Health Agency, including the bidding and hiring process, the level of experience by the architects that apply for the project, the minimum requirements of the construction companies that carry out the works as well as the awareness of the users, being them: employees or the community that use the medical and dental services.

The inclusion of environmental targets to be met by the projects and the experience in hospital building projects or the specific formation in the health area is essential and should be part of the bidding processes in order to foster changes in the results presented.

REFERENCES

Brasil. 2002. Resolução. *Regulamento técnico para planejamento, programação, elaboração e avaliação de projetos físicos de estabelecimentos assistenciais de saúde*. Ministério da Saúde. Resolução-RDC 50 de 21.02.2002. Brasília: ANVISA-Agência Nacional de Vigilância Sanitária.

CIB. 2000. *Agenda 21 para a Construção Sustentável*. São Paulo: PCC-USP.

Cook, J. 2001. *Millennium Measures of Sustainability: Beyond Bioclimatic Architecture.* Florianópolis, Brasil: Proceedings of PLEA 2001 Conference – The 18th International Conference on Passive and Low Energy Architecture – Renewable Energy for a Sustainable Development of Built Environment.

GGHC-Green Guide for Heath Care, Versão piloto 2.0. 2004. *A best practices guide for healthy and sustainable building design, construction and operations*: GGHC.

Góes, R. 2006. *Manual prático de arquitetura para Clínicas e Laboratórios.* São Paulo: Edgar Blucher.

Gil, A. C. 1996. *Como elaborar projetos de pesquisa*. São Paulo: Editora Atlas.

Kastrup, L.F. 2006. *Tecnologia de Geração Limpa a Serviço da Promoção da Saúde*; Dissertação (Mestrado em Saúde Pública). São Paulo: Faculdade de Saúde Pública da Universidade de São Paulo.

PMV-Prefeitura Municipal de Vitória. 2007. *Rede de Saúde oferece atendimento diferenciado*. In: <http://www.vitoria.es.gov.br/secretarias/saude/home.htm>. Access on 10 abr. 2007.

Silva, V.G. et al. 2000. Construction and Envi-ronmental: from theory into practice, *The Role of architectural decision making process in environmentally responsible building*. São Paulo: CIB/PCC.USP.

Toledo, L.C. 2006. *Uma Novidade Antiga, A busca pela Humanização*. Rio de Janeiro: In Anais II Congresso Brasileiro ABDEH-Hospital e Utopias.

USGBC-United States Green Building Council. 2005. *LEED for new construction & Major renovations version 2.2*. San Francisco: USGBC.

USGBC-United States Green Building Council. 2007. In: <http://www.usgbc.com>. Access on: 12 mar. 2007.

Yokoo, N. et al. 2005. *Comparison of the Assessment Results of BREEAM, LEED, GBTOOL and CASBEE*. Tokyo: In The 2005 Word Sustainable Building Conference in Japan 2005, 27-29 set.

Assisting the commissioning of the low-energy buildings design: from a methodology to a dynamic tool

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ABSTRACT: Low energy building arouses currently a big interest and many design solutions are explored. Nevertheless, in many cases, low energy buildings did not achieve the expected performance. This is due to the fact that the design and commissioning are confronted with important difficulties; especially, the lack of frequent evaluation of important decisions made all along the design process, and the management of information flow. This paper presents a methodology and a toolbox for assisting the commissioning of low-energy buildings design.

1 INTRODUCTION AND CONTEXT

Low energy buildings represent one of the most important solutions to decrease the greenhouse gas emission. These kind of advanced buildings represent a system composed of complexes subsystems (Envelop, HVAC system etc.). Its design can't be realized as a result of an intuitive design but as a constantly evaluated reflection. To reach the performance of these buildings during the design process, to limit the difficulties meet by the actors and to fill the gaps meet in the literature on the subject it is necessary to have in the same time an effective choice of solution, an effective management of information flow and an efficient commissioning process all along building life cycle (Hannachi & al. 2005).

Different projects dealt with decision-making aid, to assist the designer to make their choices and to evaluate them. A recent project realized by Hauglustaine and Azar (Hauglustaine & al. 2001), at LEMA laboratory of the University of Liege, is related to the development of a decision making aid tool for the sketch phase based on the energy consumption evaluation. The particularity of this study is the integration of the valuation of all decisions which have an impact on the building energy consumption. This evaluation permits to verify that the performances required by the owner are achieved in this stage, when the impacts of the decisions on the final building efficiency result are very important. The second advantage is that it takes into account the multiple actors and multi - criteria aspects related to the sketching process which permit to prevent the lost of information. Nerveless, this tool has his limits. It doesn't cover all design stages and can't take into account all characteristics that intervene in low energy building design.

The work of O.Akin (Akin & al., 2004) aimed at integrating a process of commissioning in the entire building life cycle. This study establishes a predefined model representing the commissioning process through the design process of HVAC systems. A second predefined model includes all information that circulates through the first model of commissioning process. This approach considers the commissioning process as a fixed process which is not representative of the reality of the building design process where a lot of unexpected events generally arrives as we saw it in real case study (Belkadi-Hannachi & al. 2006a).

Other Works realized during Annex 40 of the International Energy Agency (IEA) by Japanese (Nakahara 2004) and Netherlands teams (Op't Veld and al. 2002) integrate commissioning in the global structure of a Quality Control Model all along the life cycle of an HVAC System. The Japanese developed MQC[1] tool on simple format (Excel). It describes for each step of HVAC realization what commissioning tasks we need to realize? and, how? The Netherlands tool represents a check list where were identify all commissioning tasks that must be done during the design and exploitation of HVAC system. These tasks are classified according to different aspects of the project (Financial, administrative, technical etc.). The advantage of these tools is that they are easy to use, and cover all the design process and exploitation, but as the predecessor, they are limited to HVAC systems and supposed that we are in a perfect situation (manufacturing situation), and don't take into account the unexpected events.

These studies show the existence of decision making tools for energy control of buildings, which integrate commissioning tasks and take care of relevant information coming from different actors. Some studies permit to define and to model all commissioning tasks during design process and the information that circulates along this process. Nevertheless, these studies were done to current building. They are either limited to one step of the design process or one subsystem of the building system or don't take into account the unexpected events.

This paper presents our study which consists on developing a new methodology and a toolbox in order to assist the commissioning of low energy buildings. To create this methodology our approach starts by identifying the needs and expectation of design actors. To realize it, an investigation was done with the different building actors (Hannachi & al. 2005).

2 DESCRIPTION OF A GLOBAL METHODOLOGY FOR LOW ENERGY BUILDING DESIGN

The aim of the methodology developed is to reduce the difficulties that different building actors meet during low energy design process to reach the performance. This methodology deal with three important aspects of the design process: the decision-making aid, the commissioning and the information management. It introduces the commissioning during all the design stages, and has three purposes. First, it permits to evaluate all the decisions made and linked to energy performance, secondly, it permits to control the flow information circulation, and third, it permits to manage the unexpected events by proposing an upgradeable commissioning.

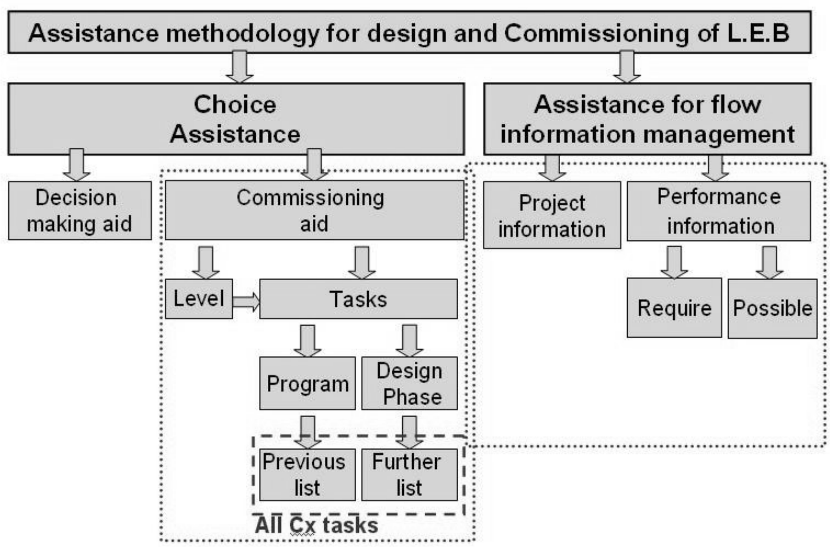


Figure 1: Representation of the structure of the global methodology for design low energy buildings

[1] *MQC* : Model Quality Control

Figure 1 illustrates the structure of this methodology. This methodology gets involved in two levels (Figure 2):

1. Choice assistance
2. Management of information flow assistance

At the first level, the methodology assists the building actors in:

- The definition of the commissioning plan. This is realized by the definition of all the commissioning tasks that the commissioning committee needs to apply in a particular case of low energy building.

  This part is created in two steps. The first step permits to define the previous or preliminary commissioning plan. This plan is developed after the assessment of the advisable level of the commissioning (heavy, light, and medium) and the study of the program (performance, regulation etc.). A further list is defined depending on evolution of the project. It will update the preliminary plan according to new information introduced by the different scenarios choices determined by the design team.
  The results of the commissioning task will determine if we should pass to the next step of the design process or not. If the results are not appropriate, the design team will define another scenario. Then the new scenario will be evaluated.

- The decision making aid.

At the second level, our methodology aims at providing assistance to manage complex and large information flow in the design and the commissioning process. It will assure that the design team disposes of all the necessary information to optimize the design choices. It will avoid drifts due to lost of information and will facilitate the information exchange between the actors. This methodology will permit to structure the information in addition the help in commissioning and decision-making aid. It will also assist the commissioning committee to extract the pertinent information to realize the commissioning task. This assistance will be based on the information related to the design team choices, the owner requirements, the environmental possibilities, technical information etc. (Figure 3).

The aim of this study is to develop a prototype of the tools that compose the commissioning toolbox assistant and apply this methodology. To create the appropriate tools that will be used by the building actors, we study real cases of low energy buildings: a rehabilitation of social housing in Fontenay Sous Bois (France), and a realization of new building in the University of La Reunion (France) (Belkadi-Hannachi & *al,*2006 a). These experiences permit us first to validate the hypothesis of evolutionary commissioning than to create the commissioning toolbox.

3 PRESENTATION OF THE COMMISSIONNING TOOLBOX ASSISTANCE FOR COMMISSIONNING PLAN DEFINITION

The objective of the developed toolbox is to assist the design team to reach the performance established by the owner in the program, all along the design, realization and operation phases. This tool box is decline into two tools as illustrated in the figure 2. The first tool is called static tool. This tool has two functions, it will assist the commissioning committee to define the preliminary commissioning plan and participate in the information management. The second tool is called Dynamic tool. In addition of the commissioning and the information assistance, it assists in decision making aid. This tool will be used by different actors as represented in figure 2, the owner, the commissioning committee, the design team and patrimony manager. We focus our work on the commissioning part of this tool box.

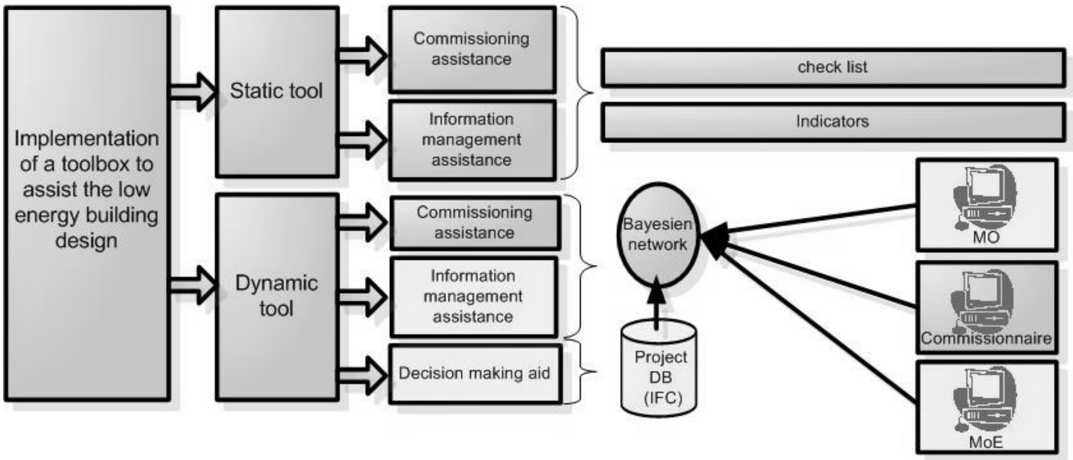


Figure 2: Representation of the structure of the toolbox applying the global methodology

The static tool is called static because it's based on all the information related to the program, the owner requirement, the environment etc. to define a preliminary plan define during the beginning of each project. This plan contain generic and fix commissioning tasks common to all project that are made in a common situation.

The dynamic one is called dynamic because it makes an update of the first plan depending on the new information added during the progress of the project by adding tasks if it's necessary.

3.1 Description of the assistant tool for the definition of the preliminary commissioning plan

The preliminary commissioning plan elaboration is inspired from some works done during annex 40 of AIE (Annex 40, 2004), from international standards as "PassivHaus" in Germany (Passivhaus) and "Minergie" in Swiss (Minergie) and from low energy buildings experimental project feed-back (Belkadi-Hannachi & *al,* 2006a).

The static tool permits to define four generic commissioning plans including some simple indicators. Each generic plan or check lists depends on the level of performance defined by the owner: regulation, efficient, very efficient and "BEPOS"[2]. These levels are defined in the research project BEPOS which is realize at the present time in Sustainable department of CSTB (Chlela and al., 2006). They correspond to: the French regulation as RT 2005 (RT2005), efficient as "Minergie" Label, very efficient as "Passivhaus" or Minergie P labels and BEPOS are Building's which produce more energy then they consume as zero energy building. For each level, a package of solution is defined and the commissioning tasks are related to them. Each check list cover two complementary parts: management and performance tasks evaluations.

The management part includes all tasks that concern the information management (good definition of needs, file exchange, etc.), the realization of all sub tasks of each step (site study, diagnostic in-site, etc.), the delay, the financial estimation, etc.

The performance part is divided into four rubrics: architectural, envelope, system, energy. The architectural rubrics are based on bioclimatic principles. The envelope field covers the technical aspects. The system's field includes the categories depending on the system type: production, distribution and emission. The energy used for the project: Sustainable Energy (possibilities, dimension calculation, etc.) and others. And the internal gains which have to be integrated in the design of all this rubrics (Belkadi-Hannachi & al. 2006b).

[2] *BEPOS* : Bâtiment à Energie POSitive

The management check lists were common for the three generic check lists. The architectural one depends on the type of the building concept (Passive Sustainable building or Active Sustainable building). The envelope, system and energy check lists change, function of the performance level (the package of solution depending of each performance). All commissioning tasks are classified into three categories function of their impact on the performances (very important impact, medium impact and low impact). Depending on the risk level and the strategy of the owner, this one can choose the commissioning level, the field (architectural, envelope etc.), and the detail level (global, system, component) (Figure 3) he wants to commission.

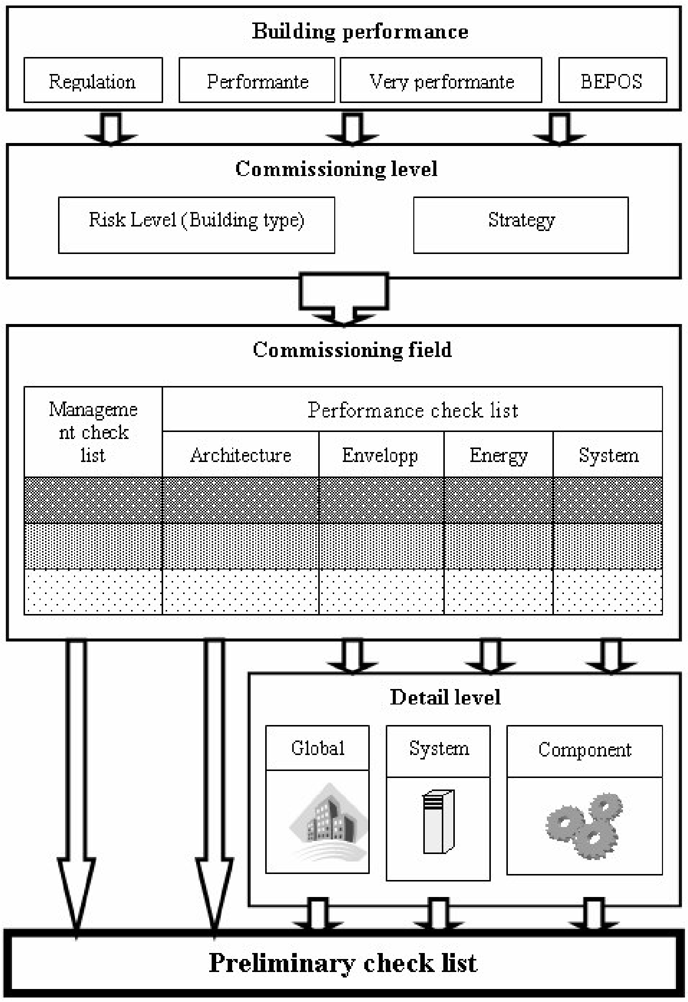


Figure 3: Representation of preliminary check list specification

All the commissioning tasks are classified into a data base according to the structure described in the figure 3 and three other factors: the climate, the building typology, the stage of the design process. Son depending on these three factors, this check list can be adapted to the project depending of the commissioning level, the detail level of the project, the performance level and the application field. Some simple indicators are implemented to clarify some tasks or to add information about it. They have to be easy to manipulate especially in the beginning of the project where the information are poor, but also all along the other steps of the project.

An exhaustive check list will be too large and to tedious to develop and use. In the reality it will be difficult to develop a check list that covers the entire domains, and all the detail level, and impossible to prevent all the unexpected events. For this reason, we decide to develop a more dynamic check list which permits to go through the detail and to manage the unexpected events by adding commissioning tasks according to the development of the project.

3.2 Description of the assistant tool for the definition of the complementary commissioning plan

The complementary commissioning plan has several objectives: it anticipates the drifts due to a difficult communication between actors (knowledge, experience etc.), it manages the unexpected events (bad diagnostic etc.), it permits to take into account the detail phases, and it permits to guaranty that all information are considered.

This list is defined by an analyzing, a quick diagnostic of the states changes of the project and comparing the result with the established performance and preliminary information. This comparison allows detecting the change that can influence the performance and put in front a warning. Each warning represents the commissioning task that must be realized in order to verify the real impact of this change.

To avoid a systematic and irrelevant warning, this study makes the choice of realizing a quick diagnostic of the project (based on incomplete information) by using the probability, and particularly a Bayesien network[3] (Réseaux bayesiens. 2004). Bayesian networks are frequently used in decision making aid systems. The aim of the tool is to relate the causes and their effects. It can estimate the probability that the design project will reach the required performances. Inversely it will be possible to locate which project characteristics have to be modified to reach the performance. That represents the part of the decision-making aid.

This tool can be use by different actors of the building design, and during different stage of his process as illustrated in figure 4. Firstly by the owner to define his program, by the design team to help them in their different choices during the design, the construction and the reception of the project, the patrimony manager if he has to renovate his building or something like this and the commissioning committee all along the building life cycle to verify the efficiency of the choices done and the field that needs more attention. The tool permits to capitalize the information that can be used depending on the way we use this network for the decision making aid: top-down or bottom-up. It important to notice that the same actor can't evaluates and gives advice on a project in a same mission because he can't be judge and jury in the same time.

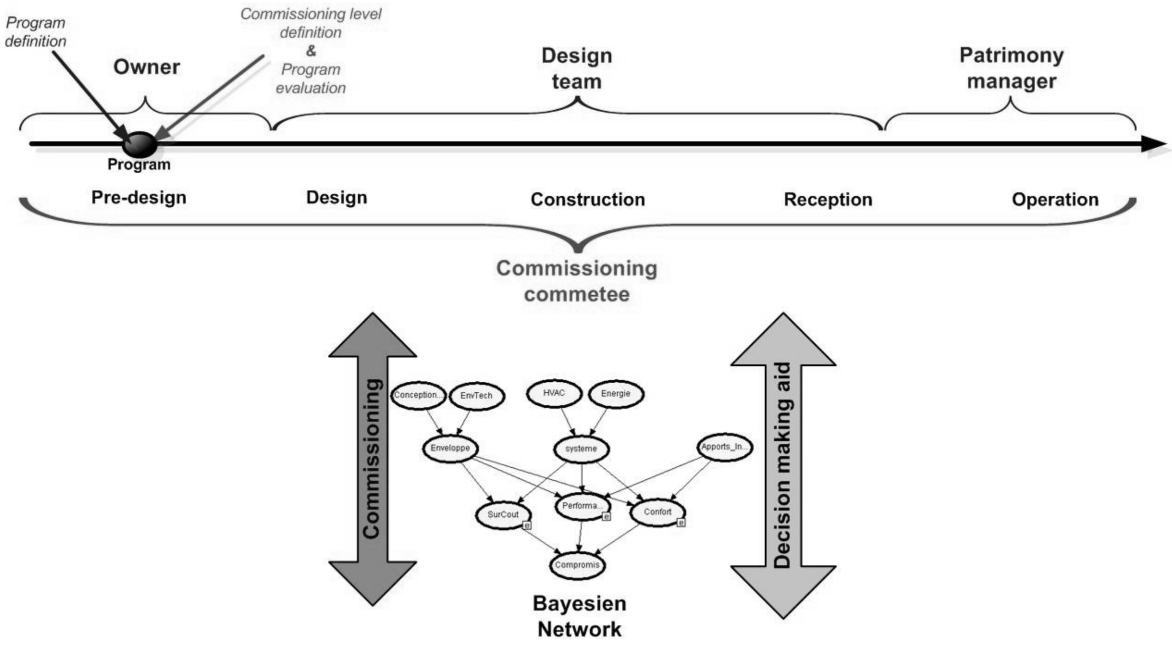
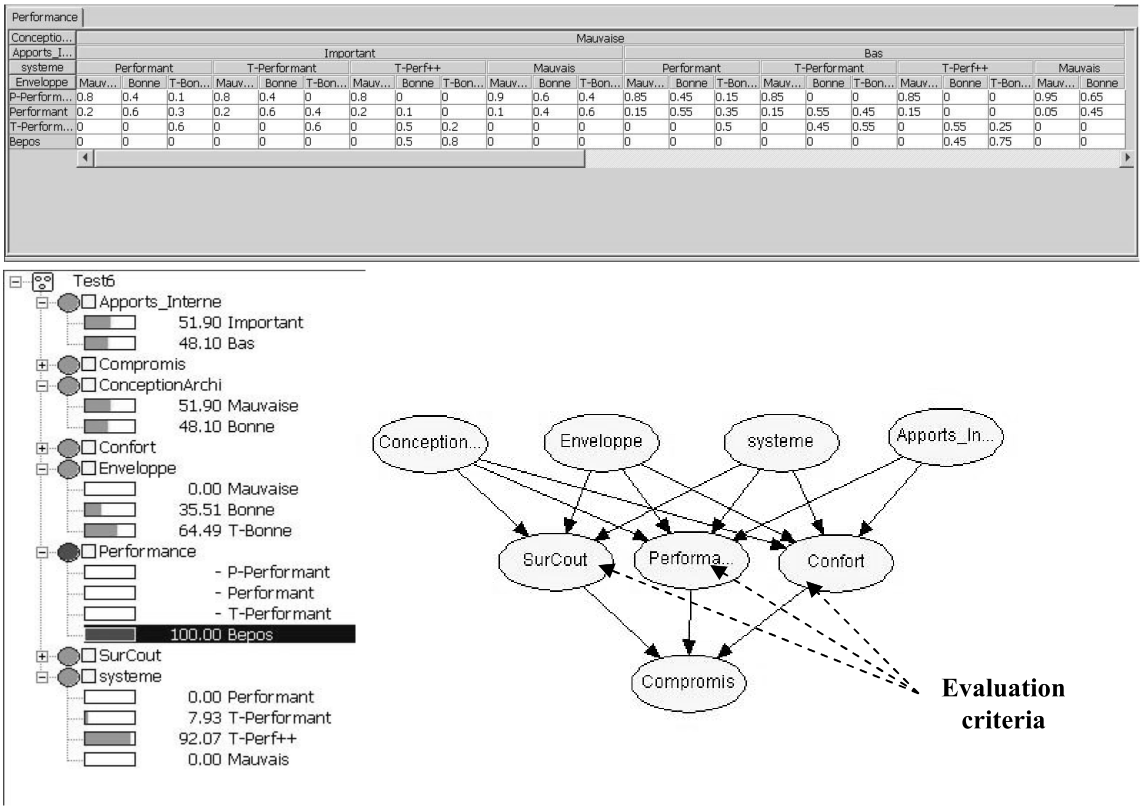


Figure 4: Representation of the application field of the Bayesien Network

[3] *Bayesian network* is used to model a domain containing uncertainty in some manner. This uncertainty can be due to imperfect understanding of the domain, incomplete knowledge of the state of the domain at the time where a given task is to be performed.

During this study we work on the commissioning part and particularly on the first step of the design process. According to the commissioning, this tool has two functions. It permits to define the real commissioning level depending on the available information and to define the complementary commissioning plan, to update the preliminary one.
As illustrated in figure 2, the dynamic tool can extract the information it needs from a database of the project (or a generic information model), but also information integrated manually by the commissioner (when the information are not digitalize, in program phase for example). This sum of information will be analyzed using a Bayesian network to define the probability to reach the performance considering these choices. Depending on the percentage of the probability to reach the performance, this tool has to extract the parts of the project that possibly make problem, then it produces a list of commissioning tasks that have to be done to verify it. The advantage of the use of the Bayesian network is that it is able to diagnostic a state of the project using incomplete information.



Performance

Conceptio...	Mauvaise											
Apports_I...	Important											
systeme	Performant			T-Performant			T-Perf++			Mauvais		
Enveloppe	Mauv...	Bonne	T-Bon...	Mauv...	Bonne	T-Bon...	Mauv...	Bonne	T-Bon...	Mauv...	Bonne	T-Bon...
P-Perform...	0.8	0.4	0.1	0.8	0.4	0	0.8	0	0	0.9	0.6	0.4
Performant	0.2	0.6	0.3	0.2	0.6	0.4	0.2	0.1	0	0.1	0.4	0.6
T-Perform...	0	0	0.6	0	0	0.6	0	0.5	0.2	0	0	0
Bepos	0	0	0	0	0	0	0	0.5	0.8	0	0	0

Conceptio...	Mauvaise										
Apports_I...	Bas										
systeme	Performant			T-Performant			T-Perf++			Mauvais	
Enveloppe	Mauv...	Bonne	T-Bon...	Mauv...	Bonne	T-Bon...	Mauv...	Bonne	T-Bon...	Mauv...	Bonne
P-Perform...	0.85	0.45	0.15	0.85	0	0	0.85	0	0	0.95	0.65
Performant	0.15	0.55	0.35	0.15	0.55	0.45	0.15	0	0	0.05	0.45
T-Perform...	0	0	0.5	0	0.45	0.55	0	0.55	0.25	0	0
Bepos	0	0	0	0	0	0	0	0.45	0.75	0	0

Figure 5: Representation of a little Bayesien Network

As illustrated in the figure 5, the diagnostic is done on three evaluation criteria: the performance related to the energy consumption, the comfort and the additional cost (in comparison with common building cost). In this example we limit the network to one level of choices that was represented by four nodes (design, envelop characteristic, systems and internal gain). For each node there are different choices and for each one a percentage of impact on the different evaluation criteria is defined. All these information are integrated in a node table represented in the top of the figure. The result of the diagnostic is represented by a percentage of probability to reach the performance, the comfort and the additional cost considering the different choices, as represented in the left of the figure 5.

4 CONCLUSION

We present in this article the global methodology we develop for an efficient design process of low energy buildings. This methodology is divided in two levels: choice assistance and information flow management assistance. The choice assistance is composed on two points: 1) Decision aid, and 2) commissioning assistance. In order to apply this methodology the specifications of toolbox was defined. This toolbox is composed of tow parts: static tool and dynamic tool. The static one is based on a database of commissioning tasks. It permits to compose of generic and preliminary commissioning plan and simple indicators. This commissioning plan can be adapted to the project depending of the performance level, the commissioning level, the detail level of the project and the application field. The second part of the toolbox is dynamic. It permits to update the first commissioning plan and to assist on the decision making aide. This tool takes into account the unexpected events, the anticipation of the drifts, the details phases, and the efficiency of information flow. It's based on Bayesian Network to do a quick diagnostic and evaluate the probability to reach the performance, the comfort and gives the additional cost according to the choices done in each step of the project. The information management assistance is integrated in each of these two tools, by adding a commissioning tasks or the definition of a common database. We will concentrate our future work on the finalization of the dynamic tool, the illustration of its efficiency and the experimentation of this toolbox on real cases.

REFERENCES

- Akin, O., Turkalsan-Bulbul, M.T, Gursel, I., Garrett Jr, J.H., Akinci, B., Wang, H., 2004, *"Embedded Commissioning for Building Design".* International Conference for Enhanced Building Operations, ICEBO 2004, Paris, France.
- Annex 40 reports, 2004, Commissioning tools for improved energy performance, Results of IEA ECBCS Annex 40.
- Annex 47, http://www.commissioning-hvac.org/newannex.aspx
- Belkadi-Hannachi, NK., Jandon, M., Vaezi Nejad, H., Guéna, F., Diab, Y., 2006, *"Commissioning aid and decision making assistance tool 'Implementation & Assessment' – cases study*", 6th International Conference for Enhanced Building Operations, ICEBO 2006, Shenzhen, China.
- Belkadi-Hannachi, NK., Jandon, M., Vaezi Nejad, H., Guéna, F., Diab, Y., 2006, *" Specifications for commissioning aid and decision making assistance tool",* 7th International Conference on System Simulation in Buildings, SSB 2006, Liege, Belgium. (Under preparation)
- Chlela, F., Fleury, E., François, C., Quenard, D., Weckstein, M., 2006, *« Bâtiments à faible consommation » : << Facteur 4 >>,* Tome 1 : « Approche exemplaire des projets et des acteurs »*,* realised in Sustainable departement in CSTB.
- Hannachi, N.K, JANDON, M., Vaezi Nejad, H., 2005, *"Methodology for information Flow Management in the Commissioning of low energy buildings"*, 5th International Conference for Enhanced Building Operations, ICEBO 2005, Pittsburgh, USA.
- Hauglustaine, J-M., AZAR, S., 2001, *"Interaction tool aiding to optimise the building envelope during the sketch design",* LEMA – University of Liege. Seventh international IBPSA Conference. Rio de Janeiro Brazil.
- Minergie, consulted on 2005/2006, http://www.minergie.ch/fr/.
- Naïm P., Wuillemin P-H., Leray P., Pourret O., Becker A., 2004, "*Réseaux bayésiens* " edition EYROLLES, 2eme Edition
- Nakahara, N., 2004, *"Japanese vision of commissioning process and Asian view",* International Conference for Enhanced Building Operations, ICEBO 2004, Paris, France
- Op't Veld, P., Huygen, C., Consulting Engineers BV, Maastricht, Pays-Bas. Paul Ramsak, Novem bv, Sittard, PAYS-BAS, 2001, *"MODEL QUALITY CONTROL (MQC) AND COMMISSIONING FOR HVAC SYSTEMS"*. Paper submit for the first Annex 40 meeting.
- Passivhause, consulted on 2005/2006, http://www.passiv.de/.
- RT 2005 *"Réglementation thermique 2005 – Guide réglementaire",* CSTB, 2005

Selecting aspects and indicators in environmental assessment methods for buildings

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ABSTRACT: It is tacitly understood that comprehensive environmental assessment methods cover the most significant environmental aspects of the intended assessment conditions. However, depending on the purpose and target-group of the method, more or fewer aspects and indicators may be included. In the development process of a Swedish environmental rating method for buildings, different approaches for selecting aspects were discussed and tested. In addition, possible indicators that measure the selected aspects were tested with regard to their environmental relevance, cost-effectiveness, etc. This procedure thus enabling a discussion of the appropriateness of different indicators used in existing environmental assessment methods for buildings. The analysis of this paper is restricted to indoor environmental quality (IEQ) but can be applied on all assessment areas of similar methods.

1 INTRODUCTION

The path towards a sustainable building sector has during the last decade generated numerous comprehensive environmental assessment methods for buildings. The methods have mainly been developed as a means for architects, planners, authorities, contractors and property managers to formulate environmental targets and to clarify options for achieving these targets. In addition they can provide environmental information to building users and other stakeholders. These initiatives are mainly national and are thus adapted to national conditions with respect to scope, legislation, stakeholders, etc. Examples of such methods include LEED in USA (Kibert, 2005), CASBEE in Japan (Murakami, 2005), and EcoEffect in Sweden (Assefa *et al.*, 2007). These methods were commonly developed in collaboration between authorities, representatives of the property and construction sector and, sometimes, universities. An initiative developed in international collaboration includes the GBTool (Cole and Larsson, 1999). A general conclusion when browsing the literature on assessment methods is that standpoints and considerations behind the choice of included assessment areas (further referred to as *aspects*) and indicators are difficult to find. Even though it is perceived as self-evident that environmental indicators should be environmentally relevant, it has seldom been discussed how this can be achieved.

To face the sustainability challenges of the sector, major stakeholders in the Swedish building and property sector, including the Swedish government, municipalities and companies, have started an initiative embracing a number of commitments for each participant (ByggaBoDialogen, 2003). One commitment reads that all new buildings and 30% of existing buildings should be classified with respect to health and environmental performance before 2009 (ByggaBoDialogen, 2003). Two research & development projects were therefore initiated to develop such a national rating method, applicable to residential buildings as well as offices, schools, etc. (Sundkvist *et al.*, 2006). The work presented in this paper has been pursued in one of these R&D projects. The intended wide application of this method raises the issue of how to strive for making the method simple without totally losing the scientific relevance.

The aim of this paper is thus to exemplify possible approaches for selecting aspects and indicators to be included in environmental assessment methods for buildings and to apply these approaches within the framework of the above-mentioned R&D project. The method referred to will cover many aspects, but this paper deals with aspects related to indoor environmental quality (IEQ).

2 APPROACHES FOR SELECTING ASPECTS

If it is important that the number of indicators be kept limited, the selection procedure of what environmental aspects to be included in a method become increasingly important. That is, an assessment of what would be the most significant environmental aspects ought to be made (compare with ISO, 2004). The R & D project used as a case study in this paper is such an example since the method is expected to be comprehensive, have a wide dissemination and be grounded in scientific evidence.

For IEQ, we mean with *aspects,* the physical indoor conditions that may give rise to health problems if unnormal; e.g. *indoor air quality, thermal climate, noise & acoustics* and *daylight conditions*. In this sense, the notion aspect is used as a way to structure the content of an assessment method. However, it is the problems for human health that different physical conditions in a building cause, that is of interest to measure by the indicators used in the method. The following sections will therefore treat different approaches to identify the most significant building-related health problems related to IEQ. Nevertheless, for practical reasons, the notion aspect is used in this text.

Five approaches were tried out in the discussions of what aspects to include in the new Swedish, rating method. They include to select aspects based on the *severity* and *extent of IEQ problems for man, official environmental objectives, legislation and current practice in other methods.*

2.1 *Severity and extent of IEQ problems*

Two approaches for establishing the significance of environmental problems, for instance used in the DALY (Disability Adjusted Life Years) work (Murray and Lopez, 1996), is to analyse the severity and extent of different problems. A literature review of the severity (i.e. the grade of disability a building-related problem causes) and extent (i.e. the number of affected people in Sweden) of building-related IEQ health problems was therefore performed in the project (Malmqvist and Glaumann, 2007). In addition, verified causal relationships between physical factors of the indoor environment and health problems were reviewed, as well as stressor levels in society. This review can be summarised as in Table 1, which can be used as a basis for discussing the selection of what aspects to include in the method. Severity and extent are here kept divided. However, to use them in combination is one way to interpret the significance of different health problems.

Table 1. Severity and extent of building-related IEQ problems.

Problem	Severity	Extent
Lung cancer from radon gas exposure	Can be fatal.	Approx. 0,005 % of the Swedish population (Pershagen, 1993).
Legionnaire disease	Can be fatal.	Approx. 0,005 % of the Swedish population (Socialstyrelsen et al., 2001).
Allergy	Can be fatal.	Approx. 0,05 % of Swedish children have asthma that can be caused by damp buildings (Bornehag et al., 2001; Bornehag et al., 2004).
SBS (Sick Building Syndrome)	Health symptoms that endure also after exposure.	Approx. 7% of the Swedish population experience at least one SBS symptom and relate it to the dwelling (Socialstyrelsen et al., 2001).
Sleeping	Health symptoms	Approx. 2 % of the Swedish population (Environmental

disturbances from traffic noise	that endure also after exposure.	Objectives Council, 2005).
Traffic noise annoyance	Discomfort when exposed.	Approx. 9% of the Swedish population (Socialstyrelsen et al., 2001).
Annoyance of neighbour noise	Discomfort when exposed.	Approx. 9% of the Swedish population (Socialstyrelsen et al., 2001).
Installation noise annoyance	Discomfort when exposed.	Approx. 3% of the Swedish population (Socialstyrelsen et al., 2001).
Annoyance by too cold indoors	Discomfort when exposed.	Approx. 12% dwellers in multifamily buildings (Norlén and Andersson, 1993).
Reduced working ability caused by too hot indoors	Discomfort when exposed.	No Swedish data found.
Reduced working ability caused by too hot indoors	Discomfort when exposed.	No Swedish data found.
Annoyance by too little day-light indoors.	Discomfort when exposed.	No Swedish data found.
Annoyance by too little direct sun-light indoors.	Discomfort when exposed.	No Swedish data found.
Reduced working ability caused by sun glare.	Reduced working ability	No Swedish data found.
EMF sensitivity	Health symptoms that endure also after exposure.	Approx. 3% (self-reported) of the Swedish population (Socialstyrelsen et al., 2001).
Children´s leukaemia	Can be fatal.	Approx. 0,00005 % of Swedish children (Socialstyrelsen et al., 2001).
Poisoning, infection, corrosion injuries from bad tap water	Acute diseases.	No Swedish data found however approx. 14 % of Swedish permanent residents and as many holiday residents depend on tap water from individual wells (Socialstyrelsen, 2006).

2.2 *Swedish official and sector objectives*

Another approach is to rely on societal intentions. In Sweden, 16 national environmental quality objectives with acquainted sub-goals have been formulated in a broad dialogue and decided on by the Swedish Parliament in consensus. These objectives and sub-goals can thus be seen as covering the most significant environmental aspects as judged by the society. The IEQ aspects that these objectives bring up include *indoor air quality (ventilation), indoor air quality (radon gas), noise & acoustics (traffic noise) and tap water quality* (Malmqvist and Glaumann, 2007).. In addition, objectives for the property and construction sector have been formulated and agreed on by a large number of companies and organisations in Sweden. These objectives have more general formulations but their focus is on *indoor air quality* (ByggaBoDialogen, 2003; Byggsektorns Kretsloppsråd, 2003).

2.3 *Legal requirements*

A similar way to interpret what the society judges as most important is the current legislation, at least the mandatory rules. However, legislation is just one instrument for authorities to tackle a problem. Thus, there may be other aspects that could be considered as significant that are not covered by the mandatory rules. There are only two more specific mandatory Swedish rules that relate to IEQ, The compulsory ventilation control Act and the Swedish Chemicals Inspectorate's Code of Statutes related to highest limited formaldehyde emissions from construction boards.That is, both these rules relate to *indoor air quality.*

2.4 *Current practice in existing methods*

Finally, it can also be expected that the assessment of significant environmental aspects already has been performed and is thus reflected in the content of existing methods. For this reason we made a thorough inventory of comprehensive environmental assessment methods for buildings. The most well-known and accessible non-Swedish methods were included as well as two well-known Swedish methods. For methods with different modules for the design or operation phases, the module for the operation phase was chosen since the new Swedish rating method was expected to assess the performance of existing buildings. Issues related to embedded hazardous substances like PCB or asbestos are in some methods treated as IEQ aspects whereas in other methods they were treated separately. In this compilation they are not included since they were treated in a separate way in our project. Table 2 shows what aspects the reviewed methods include.

Table 2. Included IEQ aspects in a selection of comprehensive environmental assessment methods for buildings.

IEQ aspect	Health problem	Included in methods
Indoor air quality	Allergy, SBS	EcoEffect (Assefa et al, 2007), LEED (Kibert, 2005) GBTool (Cole and Larsson, 1999), CASBEE (Murakami, 2005), Ecoprofile (Dyrstad Pettersen, 2000), BREEAM Office (BRE, 2006b), Swan label (SIS Ecolabelling, 2005), Miljöstatus (Miljöstatus, 1999).
	Legionnaire disease	EcoEffect, CASBEE, BREEAM Office, Miljöstatus.
	Lung cancer (radon gas)	EcoEffect, LEED, Swan label, Miljöstatus.
Noise & Acoustics	Sleeping problems, etc.	EcoEffect, GBTool, CASBEE, Ecoprofile, Ecohomes (BRE, 2006a), Miljöstatus.
Thermal climate	Discomfort	EcoEffect, LEED, GBTool, CASBEE, BREEAM Office, Miljöstatus.
Daylight conditions	Discomfort	EcoEffect, LEED, GBTool, CASBEE, BREEAM Office, Ecohomes, Miljöstatus.
Illumination	Discomfort	EcoEffect, LEED, GBTool, CASBEE, Ecoprofile, BREEAM Office, Miljöstatus
Electro-magnetic fields	EMF sensitivity	EcoEffect, Miljöstatus.
Tap water quality	Div. health problems	-

2.5 *Selection of aspects through the different approaches*

Based on the reviews above, we may summarise what IEQ aspects would be selected if considering the most severe problems, the most extensive problems, Swedish official objectives, Swedish mandatory rules and current practice in existing assessment methods. The results are presented in Table 3. The aspects mentioned in the first column in Table 3 are related to problems that can be fatal or for which the health symptoms endure even after exposure. It can be argued whether noise and acoustics would fit in this category. However, sleeping disturbance has been categorised as a disease by the Swedish National Board of Health and Welfare (Socialstyrelsen et al, 2001).

Table 3. Priority of IEQ aspects related to five selection approaches

Severity of problems	Extent of problems	Swedish official objectives	Swedish mandatory rules	Current practice
Indoor air quality – radon Indoor air quality – legionella Indoor air quality – allergy related Noise and acoustics – traffic noise Magnetic fields – childrens' leukaemia Tap water quality	Indoor air quality – SBS related Noise & acoustics Thermal climate – cold Electromagnetic field – EMF sensitivity	Indoor air quality – ventilation Indoor air quality - radon Noise and acoustics - traffic noise Tap water quality	Indoor air quality - ventilation Indoor air quality - formaldehyde	Indoor air quality Noise and acoustics Thermal climate Daylight conditions Illumination

The summary displays that different selections of aspects turn out as significant when using different approaches. It is only indoor air quality that falls out as a significant aspect to consider in all approaches, even though different sub-aspects of indoor air quality are focused on. Noise & acoustics falls out as important for four of the five approaches.

3 SELECTION OF ENVIRONMENTAL INDICATORS

The means to assess specific aspects in assessment methods are often called indicators. Indicators provide information or describe specific phenomena. They are used in the absence of precise measures or when it is too costly to make more accurate evaluations, hence their frequent use for environmental assessments. Nevertheless, selecting indicators is a compromise between theoretical and practical requirements. For understanding and testing indicators with respect to such requirements, the following set of theoretical and practical criteria was suggested by Malmqvist and Glaumann (2006):

- Theoretical criteria
  - Validity (to what extent is the problem associated with the aspect measured?)
  - Accuracy (how accurately is the problem measured?)
  - Repeatability (do repeated measurements produce the same result?)
- Practical criteria
  - Influence (to what extent can the building proprietor influence the indicator?)
  - Intelligibility (how easy is it to communicate the indicator?)
  - Cost (how costly is it to collect data and calculate the indicator?)

Such an analysis can for instance be done by scoring indicators with regard to each criteria, preferably by discussing in a group.

3.1 *Testing possible indicators for inclusion in the rating method*

In order to find relevant environmental indicators to measure the aspects that were to be included in the new, Swedish rating method, an inventory of indicators in existing methods, standards, guidelines, authority recommendations, etc. was performed. A gross list of indicators was then analysed with regard to the theoretical and practical criteria specified above

(Malmqvist and Glaumann, 2007). An important issue here is that validity is a measure of how well the indicator monitors the problem one wants to know something about. The more directly the problem is monitored, the higher the validity, or in other words, the environmental relevance. Thus, we argue that validity should be seen as superior to other criteria when selecting indicators for environmental assessments.

The analysis of the gross list of indicators displays some interesting results. If considering the indicators used in the reviewed comprehensive methods, they show a great variety. Some methods have an emphasis on indicators that indirectly measures the problems, for instance LEED, CASBEE, Ecoprofile and BREEAM office. However, there are also comprehensive methods that use indicators that in a more direct way measure problems, like EcoEffect and GBTool. Examples of indirect indicators include "controllability of indoor air quality or indoor air temperature" or indicators like verifying whether anti-glare measures have been taken or if good carpet materials have been used. Such indicators have a low validity according to the reasoning above. In contrast, occupant surveys are seen as having high validity since they measure perceivable problems in a direct way.

Theoretically, indicators that are judged to be strong at all the criteria above are the ones that theoretically are the most interesting to include in the method. Nevertheless, in practice other considerations may have to be met. For instance, IEQ indicators like "approved ventilation" (as an indicator of the health problems related to an inferior indoor air quality) and "hot water temperature" (as an indicator of risk for legionella contamination) have a rather low validity. Yet, they are simple indicators that are quite cheap to measure with rather a good accuracy. Since there may be few good alternatives, it is likely that similar indicators have to be chosen despite their shortcomings.

4 DISCUSSION

The approaches presented in this paper for selecting significant environmental aspects to be included in environmental assessment methods for buildings have all both strengths and weaknesses. To make a selection based on the severity and extent of IEQ problems can be ambiguous. For instance, there is a need to judge whether a severe problem should be valued as equally significant as an extensive one. In addition, problems can be more or less severe and extensive. Therefore, relying on official objectives or mandatory rules is less open for interpretation than selecting aspects according to the severity and extent of problems. However, since there is a displacement in time between new scientific evidence and the institution of objectives and laws, updated reviews are often necessary. In addition, under current Swedish conditions official objectives and regulations exist that may be relied on when selecting aspects. However, if such officially agreed-on intentions are absent, it will naturally not be possible to use such an approach. To rely on mandatory rules also has the evident drawback that legislation is only one way for authorities to deal with significant problems in society.

It is common that new methods build on previous initiatives (Cole, 2006). Relying on existing methods for selecting aspects and indicators has the advantage of recognition and, as a consequence, supports practical implementation. However, methods have been developed in different contexts, for different target groups and applications. To rely on current practice is therefore a doubtful approach when selecting aspects. In addition, most comprehensive methods are extensive and thus they do not provide enough evidence for prioritisation between aspects.

Table 3 shows that the aspects considered by the Swedish official objectives correspond quite well to the aspects that fall out to be significant when assessing the severity of problems. Existing methods often include thermal climate, probably because of the extent of this problem. In addition, daylight and illumination conditions are included in many comprehensive methods, despite the fact that no other selection approaches reveal their significance. Noise & acoustics stand out since it is not included in the well-known methods LEED and BREEAM (Office) despite causing both severe and extensive problems as well as being prioritised in the Swedish official objectives.

Once aspects are selected, we suggest that indicators that as satisfactorily as possible monitor the related problems of the aspects be chosen, that is., indicators with high validity. However, other criteria like accuracy and costs are also vital. Indicators with low accuracy and that are costly to calculate will most likely not be chosen. If it only seems possible to choose indicators with low validity, complementary indicators for measuring the same aspect can be necessary. For instance, an indicator like "approved ventilation" may be complemented with asking the user´s opinion of the perceived indoor air quality.

5 CONCLUSIONS

If there is a need to limit the number of indicators in a comprehensive environmental assessment method for buildings, an approach for selecting the most significant environmental aspects to be included is appreciable. Just to rely on previously developed methods is then not enough since methods are developed in different contexts and for different purposes. In our work with a new Swedish environmental rating method for buildings we found it interesting to test a number of selection approaches. Aspects that fell out as significant in many of these approaches were then found to be well motivated to be included in the method. In addition, we judged aspects that fell out as significant when basing the selection of severity of problems and official objectives to be more prioritised. Thus, in our work we found indoor air quality and noise & acoustics (in particular traffic noise) to be the most significant aspects.

We further argue that indicators for monitoring aspects/problems be tested with regard to at least validity, cost and other criteria since such a testing procedure facilitates a discussion of pros and cons with different indicators. This feature is in particular important in methods that give weighted ratings. We have not seen such analyses of indicators in existing methods. To achieve a wide dissemination of a rating method, indicators that are possible to connect to incentives, like reduced tax and reduced insurance fees, or that are included in other mandatory systems, can be prioritised. However, since the aim is to rate environmental performance, it can be argued that the validity with respect to monitoring specific environmental aspects should be seen as superior to other criteria.

The paper has focused on building-related IEQ aspects and indicators. The approaches for selecting aspects and indicators are, however, universal and can be applied to all types of building-related environmental problems. If used it will facilitate a logical argumentation for why specific aspects and indicators are selected in different methods.

6 REFERENCES

Arbetslivsinstitutet, Arbetsmiljöverket, Myndigheten för skolutveckling, Socialstyrelsen. 2006. *Bullret bort! En liten handbok om god ljudmiljö i förskolan*. Stockholm: Socialstyrelsens kundtjänst.

Assefa, G., Glaumann, M., Malmqvist, T., Kindembe, B., Hult, M., Myhr, U., Eriksson, O. 2007. Environmental assessment of building properties – where natural and social sciences meet: The case of EcoEffect. *Building and Environment, 42(2007): 1458-1464.*

Bornehag, C-G., Blomquist, G., Gyntelberg, F., Järvholm, B., Malmberg, P., Nordvall, L., Nielsen, A., Pershagen, G., Sundell, J. 2001. Dampness in Buildings and Health. Nordic Interdisciplinary Review of the Scientific Evidence on Associations between Exposure to "Dampness" in Buildings and Health Effects (NORDDAMP). *Indoor Air, 11(2): 72-86.*

Bornehag C-G., Sundell, J., Bonini, S., Custovic, A., Malmberg, P., Skerfving, S., Sigsgaard, T., Verhoeff, A. 2004. Dampness in buildings as a risk factor for health effects, EUROEXPO: a multidisciplinary review of the literature (1998-2000) on dampness and mite exposure in buildings and health effects. *Indoor Air, 14(4): 243-257.*

BRE. 2006a. *Ecohomes 2006 – The environmental rating for homes. The guidance – 2006/Issue 1.2*. Watford, UK: Building Research Establishment.

BRE. 2006b. BREEAM Offices 2006. Pre-assessment Estimator. Management & Operation. *www.breeam.org.*

ByggaBoDialogen. 2003. Building/Living and Property Management for the Future - The Commitments. *http://www.byggabodialogen.se/EPIServer/templates/Page.aspx?id=2077.*

Byggsektorns Kretsloppsråd. 2003. *Miljöprogram 2010*. Stockholm: Byggsektorns Kretsloppsråd.

Cole, R. 2006. Shared markets: coexisting building environmental assessment methods. *Building Research & Information, 34(4): 357-371.*

Cole, R., & Larsson, N. 1999. GBC ´98 and GBTool: background. *Building Research & Information, 27(4/5): 221-229.*

Dyrstad Pettersen, T. 2000. *Ecoprofile for Commercial Buildings – Simplistic Environmental Assessment Method. Reference document*. Oslo: Byggforsk.

Emenius, G. 2003. *Indoor environment and recurrent wheezing in young chi*ldren. Solna, Sweden: Karolinska Institutet.

Environmental Objectives Council. 2005. Swedish Environmental objectives - for the sake of our children, A progress report from the Swedish Environmental Objectives Council, Swedish Environmental Protection Agency, de facto 2005. Stockholm: Naturvårdsverket.

Glaumann, M. & Malmqvist, T. 2005. Assessing the Environmental Efficiency of Buildings. In Vestbro, D. U., Hürol, Y., Wilkinson, N. (eds). *Methodologies in housing research.* Tyne&Wear, GB: The Urban International Press.

ISO. 2004. Environmental management systems - Requirements with guidance for use (ISO 14001:2004). International Standards Organisation (ISO).

Kibert, C.J. 2005. Sustainable construction. Green building design and delivery.

Hoboken, New Jersey: John Wiley & Sons, Inc.

Malmqvist, T. & Glaumann, M. 2007. Selecting aspects and indicators in environmental rating methods for buildings – indoor environmental quality. *Manuscript.*

Malmqvist, T. & Glaumann, M. 2006. Selecting problem-related environmental indicators for housing management. *Building Research & Information, 34(4): 321-333.*

Miljöstatus. 1999. *Miljöinventering & bedömning. Handledning.* Stockholm: Intresseföreningen för Miljöstatus för byggnader.

Murakami, S. 2005. Sustainability in Architecture. Tokyo, Japan: Institute for Building Environment and Energy Conservation (IBEC).

Murray, C.J.L & Lopez, A.D. 1996. The Global Burden of Disease. Cambridge MA, USA: Harvard University Press.

Norlén, U. & Andersson, K. 1993. The indoor climate in the Swedish housing stock. Stockholm: The Swedish Council for Building Research

Pershagen, G. 1993. Radon i bostäder och lungcancer: En landsomfattande epidemiologisk undersökning. Stockholm: Institutet för Miljömedicin, Karolinska Institutet.

SIS Ecolabelling. 2005. *Swan labelling of Small Houses. Version 1.3. 15 March 2005 - 15 March 2008*. Stockholm: SIS Ecolabelling.

Socialstyrelsen, Institutet för Miljömedicin, Stockholms läns landsting (Miljömedicin). 2001. Stockholm: SOS, IMM, Miljömedicinska enheten SLL.

Sundkvist, Å., Eriksson, O., Glaumann, M., Bergman, S., Finnveden, G., Stenbeck, S., Wintzell, H. 2006. Miljöklassning av byggnader - Inventering av metoder och intressenters behov (Environmental Classification of buildings – Inventory of methods and needs of the interested), (In Swedish). Stockholm: Royal Institute of Technology, Division of Environmental Strategies Research – fms.

Life cycle assessment tool for building assemblies

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It is widely recognized in the field of Green Buildings that Life Cycle Assessment (LCA) is a conceptually preferable method for determining the environmental effects of materials, rather than relying on singular material properties or attributes, such as recycled content or distances traveled after the point of manufacture. However, the LCA tools that are currently available are not widely utilized. This is exacerbated by the failure of popular green building rating systems to fully incorporate LCA. The Green Building Initiative is introducing LCA as a more prominent aspect of the material section in its Green Globes building assessment and rating system. In addition to developing an LCA tool for use within Green Globes, a generic version of the tool, *Athena EcoCalculator*, has been developed and made available free of charge so that LCA information can be easily incorporated into other guidelines and rating systems.

1 INTRODUCTION

In the past 15 years, many international, national and regional sustainable building guidelines have been developed. In North America, the LEED™ Rating System (Leadership in Energy and Environmental Development) developed by the U.S. Green Building Council (USGBC) has emerged in recent years with a high level of visibility and increasing market acceptance. Recently Green Globes™, used for many years in Canada, has been introduced into the US by the Green Building Initiative (GBI) as a sustainable building rating system and guide for commercial buildings. In the US, sustainable commercial building guidelines have also been developed at the state and regional levels in New York, Minnesota, Florida and elsewhere. In the residential sector, there are many green building programs and guidelines as well.

The future of these rating systems is unknown but there appear to be several driving forces that will shape their evolution. These include an emphasis on performance outcomes such as global warming impact, the need for regional variations, the need for variations for different building types, the trend toward more requirements rather than point-based alternatives, and more focus on actual building performance during occupancy and operation.

2 LIFE CYCLE ASSESSMENT

A key aspect of moving toward more performance-based outcomes in sustainable design is the use of Life Cycle Assessment (LCA) to determine the embodied environmental effects of materials, rather than relying on singular material properties, such as recycled content or distances traveled after the point of manufacture. However, the LCA tools that are currently available are not widely utilized by most stakeholders, including those designing, constructing, purchasing or occupying buildings.

LCA is a methodology for assessing the environmental performance of a product over its full life cycle. Environmental performance is generally measured in terms of a wide range of potential effects, such as:

- fossil fuel depletion
- other non-renewable resource use
- water use
- global warming potential
- stratospheric ozone depletion
- ground level ozone (smog) creation
- nutrification/eutrophication of water bodies
- acidification and acid deposition (dry and wet)
- toxic releases to air, water and land

All of these measures are indicators of the environmental loadings that can result from the manufacture, use and disposal of a product. The indicators do not directly address the ultimate human or ecosystem health effects, a much more difficult and uncertain task, but they do provide good measures of environmental performance, given that reducing any of these effects is a step in the right direction.

3 LCA TOOLS IN NORTH AMERICA

Current LCA-based tools in North America include BEES 3.0, which is a product comparison tool including some brand-specific data, and the ATHENA® Environmental Impact Estimator (EIE) for analysis of whole buildings and assemblies. BEES 3.0 is intended for use at the specification or procurement stages of the process. Weighting factors are used to generate overall environmental and economic scores. ATHENA® EIE is for use at the conceptual design stage. A range of indicators without weighting are generated to show environmental effects of changes in shape, design or material make-up of a building.

Recently, a new tool has been developed for use with the Green Globes™ environmental assessment and rating system for commercial buildings. With funding from the Green Building Initiative (GBI), the tool was created by Morrison Hershfield Consulting Engineers in association with the University of Minnesota's Center for Sustainable Building Research and the Athena Sustainable Materials Institute. Modeled on the Building Research Establishment's (BRE) *Green Guide to Specification*, which has been used in the U.K. for over a decade, it measures the global warming potential and other environmental impacts of more than 400 common building assemblies in low- and high-rise categories. This same approach has been proposed for the U.S. Green Building Council's (USGBC) LEED® Rating System in a report from a working group of the ad hoc "LCA into LEED" initiative that was launched in September 2004.

The LCA tool and the entire Green Globes rating system is currently going through the technical committee responsible for GBI's consensus process, which complies with American National Standards Institute (ANSI) standards. GBI has authorized the Athena Institute to make a generic version of this tool freely available for use by other green building organizations, government entities, trade associations and universities. Regional versions of the tool are being developed to better reflect life cycle impacts based on local conditions. One of these regional versions is incorporated into the Minnesota Sustainable Building Guidelines. GBI also intends for the new software to be used in a forthcoming online version of the National Association of Home Builders' Model Green Home Building Guidelines. Manufacturers can contribute relevant data to the U.S. LCI Database Project (www.nrel.gov/lci).

4 DESCRIPTION OF THE NEW LCA TOOL

4.1 *Determining Building Assemblies and Functional Equivalence*

The tool includes a list of common building assemblies for office, commercial or industrial buildings. These assemblies are broken into categories based on broad system type (exterior walls, interior walls, window systems, beams, columns, intermediate floors, and exterior roofs). One challenge in comparing groups of building assemblies is establishing functional equivalence. Developing these more detailed functional equivalence categories presented a number of issues.

Ideally, all assemblies in a defined category should have identical performance characteristics. However, assemblies are often relied upon to perform several different roles within a building. For example, an exterior wall may serve purposes related to structure, thermal resistance, fire resistance, air and vapor control, sound control, and aesthetics. This presents a complication: different users of the tool may have different intended purposes for a given assembly. For example, a structural engineer may want to compare assemblies with similar structural performance characteristics, while an architect or building science engineer may want to compare assemblies with similar thermal performance characteristics.

While it is possible to create a list of assemblies within a category with identical properties in one area, such as thermal resistance, the result would be a list where some assemblies have unrealistic components. For example, if all exterior wall assemblies must meet a certain thermal resistance, most walls would utilize levels of insulation that are atypical and unavailable.

A third functional performance issue is the fact that some assemblies are relatively uncommon or impossible to utilize for specific building types. For example, it is unlikely that a high-rise building will be constructed with wood based columns and beams, and it would be unrealistic to offer these assemblies as viable options for some building types. This is particularly relevant if the LCA data of this assembly affects the ultimate rating of other assemblies.

A last issue relates to the effect of an LCA rating on other aspects of sustainability. In general, assemblies with higher amounts of materials tend to have larger material environmental impacts than those with lesser amounts. For example, a 2x6 insulated wood stud wall will have higher material environmental impacts than a 2x4 insulated wood stud wall, if all material types within the system are the same. However, with many assemblies, material impacts represent only part of the environmental effect associated with the assembly: Their use also has operational effects, which could be significantly larger than their material effects over a building's life cycle. This raises the question of whether an LCA rating tool should promote the use of low embodied effect systems, when these systems might be a poor choice if operational issues are included for consideration.

To address some of these issues, the new LCA tool is divided into two separate parts: high-rise and low-rise construction. Note that many building assemblies were included in both building types. Low-rise buildings were considered to be four stories or less. Assemblies are broken into broad categories based solely on their use. Categories include exterior walls, interior walls, window systems, beams and columns, intermediate floors, and roofs. Factors for thermal resistance are provided for exterior walls and roofs, but solely for information purposes (they are not used to further categorize assemblies). No other functional equivalence categories are included.

4.2 *Environmental Impact Indicators*

The ATHENA™ Environmental Impact Estimator (EIE) was used to develop LCA information on each building assembly. LCA results were developed for the following indicators: primary energy (fossil fuel depletion), global warming potential, air and water pollution indices, and solid waste. Each of these environmental measures used by the ATHENA™ Environmental Impact Estimator (EIE) software is described below.

Embodied primary energy is reported in Giga-joules (Gj). Embodied energy includes all non-renewable energy, direct and indirect, used to transform or transport raw materials into products and buildings, including inherent energy contained in raw or feedstock materials that are also used as common energy sources. (For example, natural gas used as a raw material in the production of various plastic (polymer) resins.) In addition, the model and measure captures the pre-combustion (indirect) energy use associated with processing, transporting, converting and delivering fuel and energy.

Solid waste is reported on a mass basis in kilograms and includes all solid wastes generated during manufacturing, construction, replacement and demolition that are destined for landfills. No attempt has been made to further categorize emissions to land as either hazardous or non-hazardous. All other measures are indices requiring more explanation and interpretation. They have been developed because of the difficulty of using and interpreting detailed life cycle inventory results. For example, it takes considerable expertise to understand and appreciate the significance of the individual emissions to air and water. Both categories encompass a relatively large number of individual substances with varying environmental impacts.

Global Warming Potential (GWP) is a reference measure. Carbon dioxide is the common reference standard for global warming or greenhouse gas effects. All other greenhouse gases are referred to as having a "CO_2 equivalence effect" which is simply a multiple of the greenhouse potential (heat trapping capability) of carbon dioxide. This effect has a time horizon due to the atmospheric reactivity or stability of the various contributing gases over time. The International Panel on Climate Change (2001) 100-year time horizon figures have been used here as a basis for the equivalence index:

$$CO_2 \text{ Equivalent kg} = CO_2 \text{ kg} + (CH_4 \text{ kg x } 23) + (N_2O \text{ kg x } 296)$$

While greenhouse gas emissions are largely a function of energy combustion, some products also emit greenhouse gases during the processing of raw materials. Process emissions often go unaccounted for due to the complexity associated with modeling manufacturing process stages. One example where process CO_2 emissions are significant is in the production of cement (calcination of limestone). Because Athena™ uses data developed using a detailed life cycle modeling approach, all relevant process emissions of greenhouse gases are included in the resultant global warming potential index.

The *air and water pollution* measures are similarly intended to capture the pollution or human health effects of groups of substances emitted at various life cycle stages. In this case we used the commonly recognized and accepted critical volume method to estimate the volume of ambient air or water that would be required to dilute contaminants to acceptable levels, where acceptability is defined by the most stringent standards (i.e., drinking water standards). The Athena™ EIE software calculates and reports these critical volume measures based on the worst offender—that is, the substance requiring the largest volume of air and water to achieve dilution to acceptable levels. The hypothesis is that the same volume of air or water can contain a number of pollutants.

4.3 *Allocation of Points and Weighting Issues*

The new tool allows an unbiased comparison of material assemblies across a set of five environmental indicators: embodied primary energy, which stands as a proxy for fossil fuel use; global warming potential; toxic releases to air; toxic releases to water; and solid waste. In the generic version of the tool, the *Athena EcoCalculator*, the LCA impacts are directly presented with no weighting or point allocations (Figure 1).

In the Green Globes version, the goal is to translate the LCA results into points for the rating system. Rather than combining LCA scores across the five impact categories using some type of weighting so that each assembly can be assigned a single score, Green Globes will attribute points to each assembly in each impact category. This approach serves a valuable educational function because it lets the design team more readily see where they are earning their points. Points are awarded for a singular assembly by comparing its performance across each indicator measure to all other assemblies within the functional equivalence category (e.g. exterior walls for low-rise buildings). Assemblies with better than average performance across an indicator measure receive points (on a sliding scale), and the overall points for a particular assembly represent the sum of the points for each indicator category. There is no explicit weighting between indicator categories.

5 EXAMPLE OF LCA APPLIED TO BUILDING ASSEMBLIES AND MATERIALS

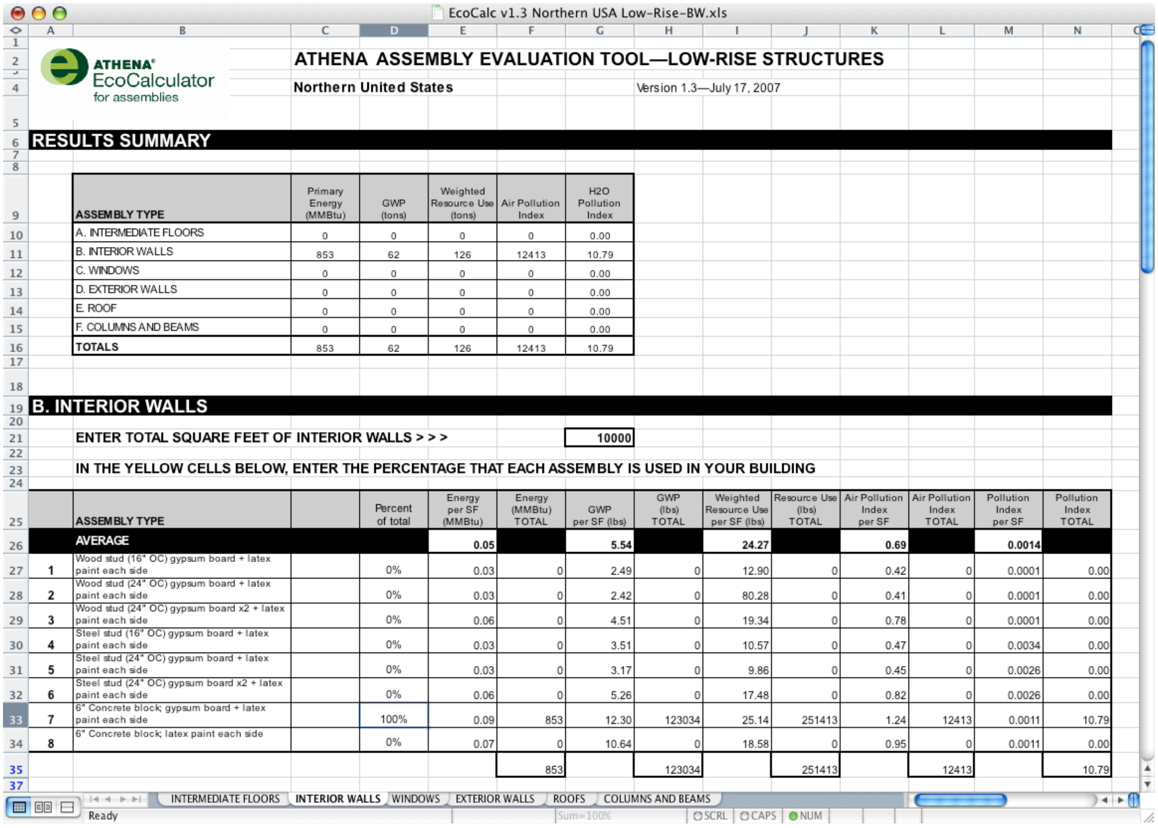
A simple assembly comparison using the ATHENA® EIE illustrates how LCA can be used to make design decisions taking proper account of environmental performance measures throughout the life of the materials. In Table 1, a given area of window assembly is compared to three typical solid wall assemblies in terms of primary energy use (read fossil fuel use), global warming potential, solid waste, air pollution index, and water pollution index.

Table 1 illustrates the extent to which reducing window area has a beneficial environmental impact looking at the materials aspect in isolation, however such a decision must be examined in a whole systems context. For example, window design choices can have direct effects on building energy use if electric lighting and related cooling energy use are reduced because windows permit sufficient daylight to enter a space. Of course, they can also affect energy consumption as a result of heat loss and radiant solar heat gain. Window design decisions also have potential LCA impacts by affecting the design of many related components and systems in a building. A high performance window designed to maximize daylighting might reduce the need for light fixtures and perimeter heating in a space, as well as help reduce the size of the mechanical system. Similarly, if a particular window is chosen with a high visible transmittance glazing to enhance daylighting, glare may be increased resulting in the need for exterior or interior shading systems with related material impacts.

These systems implications should and can be taken into account in LCA tools, such as the ATHENA® EIE, balancing any increased environmental impacts from the materials (additional glazing layers and coatings for example) against the avoided impacts from reduced operating energy use over the life of the building. Those kinds of impacts must, of course, be balanced against other functional, cost, human comfort and aesthetic criteria to optimize systems from all perspectives.

6 CONCLUSION

The adoption of LCA tools into Green Globes, LEED, and other regional rating systems represents a major step forward in what will likely be an ongoing integration of LCA into the sustainable design process. Over time, this process should strengthen the link between rating system scores and actual environmental benefits. The ultimate goal is to model the environmental impacts of whole buildings, so that rating systems can abandon the checklist approach and rate buildings based on a comprehensive model of their environmental performance, similar to the way energy modeling is done today. The final LCA tool developed in this project allows an unbiased comparison of material assemblies across a set of environmental indicator categories. The tool will be continually updated as new building product data or new assemblies emerge in the market. In addition, an alternative compliance path involving whole building LCA will be explored and possibly incorporated into Green Globes and other rating systems.



EcoCalc v1.3 Northern USA Low-Rise-BW.xls

ATHENA EcoCalculator for assemblies

ATHENA ASSEMBLY EVALUATION TOOL—LOW-RISE STRUCTURES

Northern United States

Version 1.3—July 17, 2007

RESULTS SUMMARY

ASSEMBLY TYPE	Primary Energy (MMBtu)	GWP (tons)	Weighted Resource Use (tons)	Air Pollution Index	H2O Pollution Index
A. INTERMEDIATE FLOORS	0	0	0	0	0.00
B. INTERIOR WALLS	853	62	126	12413	10.79
C. WINDOWS	0	0	0	0	0.00
D. EXTERIOR WALLS	0	0	0	0	0.00
E. ROOF	0	0	0	0	0.00
F. COLUMNS AND BEAMS	0	0	0	0	0.00
TOTALS	853	62	126	12413	10.79

B. INTERIOR WALLS

ENTER TOTAL SQUARE FEET OF INTERIOR WALLS > > > 10000

IN THE YELLOW CELLS BELOW, ENTER THE PERCENTAGE THAT EACH ASSEMBLY IS USED IN YOUR BUILDING

	ASSEMBLY TYPE	Percent of total	Energy per SF (MMBtu)	Energy (MMBtu) TOTAL	GWP per SF (lbs)	GWP (lbs) TOTAL	Weighted Resource Use per SF (lbs)	Resource Use (lbs) TOTAL	Air Pollution Index per SF	Air Pollution Index TOTAL	Pollution Index per SF	Pollution Index TOTAL
	AVERAGE		0.05		5.54		24.27		0.69		0.0014	
1	Wood stud (16" OC) gypsum board + latex paint each side	0%	0.03	0	2.49	0	12.90	0	0.42	0	0.0001	0.00
2	Wood stud (24" OC) gypsum board + latex paint each side	0%	0.03	0	2.42	0	80.28	0	0.41	0	0.0001	0.00
3	Wood stud (24" OC) gypsum board x2 + latex paint each side	0%	0.06	0	4.51	0	19.34	0	0.78	0	0.0001	0.00
4	Steel stud (16" OC) gypsum board + latex paint each side	0%	0.03	0	3.51	0	10.57	0	0.47	0	0.0034	0.00
5	Steel stud (24" OC) gypsum board + latex paint each side	0%	0.03	0	3.17	0	9.86	0	0.45	0	0.0026	0.00
6	Steel stud (24" OC) gypsum board x2 + latex paint each side	0%	0.06	0	5.26	0	17.48	0	0.82	0	0.0026	0.00
7	6" Concrete block; gypsum board + latex paint each side	100%	0.09	853	12.30	123034	25.14	251413	1.24	12413	0.0011	10.79
8	6" Concrete block; latex paint each side	0%	0.07	0	10.64	0	18.58	0	0.95	0	0.0011	0.00
				853		123034		251413		12413		10.79

INTERMEDIATE FLOORS | INTERIOR WALLS | WINDOWS | EXTERIOR WALLS | ROOFS | COLUMNS AND BEAMS

Ready | Sum=100% | SCRL | CAPS | NUM

Figure 1: Athena EcoCalculator Interface

Table 1: Wall Assembly Comparison

ASSEMBLY TYPE	Primary Energy per SF (MJ)	GWP per SF (kg)	Solid Waste per SF (kg)	Air Pollution Index	Water Pollution Index
Window system with aluminum frame Low-E silver, argon-filled glazing	622	32.31	17.08	10.08	0.0021
CIP Concrete, brick cladding rigid insulation, vapor barrier gypsum board, latex paint	238	9.79	2.81	1.63	0.0010
CIP Concrete, stucco cladding rigid insulation, vapor barrier gypsum board, latex paint	160	13.22	3.29	2.39	0.0018
Steel stud, stucco cladding gypsum sheathing, batt insulation vapor barrier, gypsum board, paint	91	5.02	1.04	1.05	0.0098

REFERENCES

Anderson, J., Shiers, D.E. & Sinclair, M. 2002. The Green Guide to Specification (3rd edition). Building Research Establishment.

Horst, S.W. & Trusty, W.B. 2003. 'Integrating LCA Tools in LEED: First Steps'. Proceedings: USGBC Greenbuild International Conference & Expo, Pittsburgh.

Trusty, W.B. 2007. 'Standards vs. Recommended Practice: Separating Process and Prescriptive Measures from Building Performance'. Presentation at ASTM Symposium on Common Ground, Consensus Building and Continual Improvement: Standards and Sustainable Building, Washington, DC.

Trusty, W.B. & Horst, S. 2002. 'Integrating LCA Tools in Green Building Rating Systems'. Proceedings: USGBC Greenbuilding International Conference & Expo, Austin, November 2002. 7 pp Published in "The Austin Papers: Best of the 2002 International Green Building Conference", Compiled by the Editors of Environmental Building News, Published by BuildingGreen, Inc., 2002, pp53-57.

RESOURCES

Athena Environmental Impact Estimator
Athena Sustainable Materials Institute
http://www.athenasmi.ca/

BEES 3.0 (Building for Environmental and Economic Sustainability)
National Institute of Standards and Technology
http://www.bfrl.nist.gov/oae/software/bees.html

Green Building Initiative
http://www.thegbi.org/gbi/

Center for Sustainable Building Research
University of Minnesota
http://www.csbr.umn.edu/

Minnesota Sustainable Building Guidelines
http://www.csbr.umn.edu/B3/

U.S. Green Building Council
http://www.usgbc.org/

Performance assessment for sustainable construction: lest we forget about the client

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ABSTRACT: Sustainability of the built environment is receiving much attention in recent times, mainly because the concept is inextricably linked with several key global issues e.g. economic, environmental, housing etc. An important aspect of these has to do with the assessment of the performance of the industry's quest for sustainability. This calls for a consideration of a well laid out approach of performance assessment. This should satisfy the multidimensional, multi-criteria concept. Hence, the need to identify the key measures, criteria, and the stakeholders becomes necessary. The authors believe that it should be addressed at the local (national) levels first, then, regional, continental, and finally at the global level. In addition, it is submitted that the client as the promoter of construction should be an active partner in ensuring sustainability. This, it is estimated, will be the necessary step towards managing sustainable construction at all levels.

1 INTRODUCTION

Sustainability of the built environment is a topic that is receiving much attention in recent times. This is mainly because the concept is inextricably linked with several key global issues e.g. economic, environmental, housing and construction etc. Howard (2000) describes sustainability in terms of the following: social progress that meets the needs of everyone, economic growth, effective protection of the environment, and efficient use of resources. Specifically, Sustainable construction has also been described as the application of sustainable development to the construction industry (AggRegain, 2007); the latter being defined as: "development that meets the present without compromising the ability of the future generations to meet their own needs" (The Brundtland Report, 1987).

Howard (2000) identifies the characteristics of the construction industry in terms of the economy, society, construction activity and materials, building operation, and transport and waste implication; and concludes that "the combined performance of these issues represents the sustainability of construction and the built environment". The European Charter on Sustainable Design & Construction (1998) provides as an introduction to its 27 principles that they (the principles) need to be "actively considered, implemented, and monitored by means of benchmarking and the application of appropriate sustainability performance indicator". Performance assessment, thus, is at the core of sustainable construction.

2 PERFORMANCE ASSESSMENT OF SUSTAINABLE CONSTRUCTION: THE DIMENSIONS/INDICATORS

The importance of performance assessment in the quest for sustainable construction has been well underscored (Walsh, 1998; Hill and Bowen, 1997; Howard, 2000; Arbor, 1999; Augenbroe et al, 1998). This could be seen as a positive development that strengthens the contribution of the built environment to the broader agenda of global sustainable development. Hill and Bowen (1997) single out four attributes (calling them “pillars” of sustainable construction) of sustainability –social, economic, biophysical, and technical –to explain the concept of sustainable construction. Howard (2000) provides a framework for assessing sustainable construction issues in: “sustainable construction –the data” as part of a project entitled “sustainable Construction – Developing an industry agenda”. Overall 7 key data categories were identified: Economic Perspectives, Construction Materials and Resources, Construction Activity, Building Operation, Recycling and Disposal, and social perspectives. These were analysed with a total of 37 items.

At a National Sustainable Building Workshop in Michigan (1999), 30 sustainability indicators were identified together with their individual criteria for assessments (Arbor, 1999). These were grouped into 5 categories: Environmental Performance Assessment, Economic, Code Issues, Organisational Condition, Stakeholder and Public Education. In a related development, Augenbroe et al (1998) detailed 4 requirements for sustainable building materials: Environmental Performance, Technological Performance, Resource Performance, and Socio-economic Performance. In addition, 15 identified drivers of change in the construction industry were highlighted: “Energy conservation measures, Land use regulations urban planning policies, Waste reduction measures, Resource conservation strategies, Indoor environment quality, Environmentally-friendly energy technologies, Re-engineering the design process, Pro-active role of materials manufacturers, Better ways to measure and account for costs, New kinds of partnerships and project stakeholders, Adoption of performance-based standards, Product innovation and/or certification, Adoption of incentive programmes, Education and training, Recognition of commercial buildings as productivity assets”. The Fundamental Matrix: 2010 lists Social, Economic, Environmental, Institutional, and Political as the construction related sustainability performance indicators.

Literature, thus, seems to be highlighting certain dimensions (indicators) by which sustainable construction should be assessed. Figure. 1 represents the summary (not exhaustive) of the 14 dimension obtainable from literature.

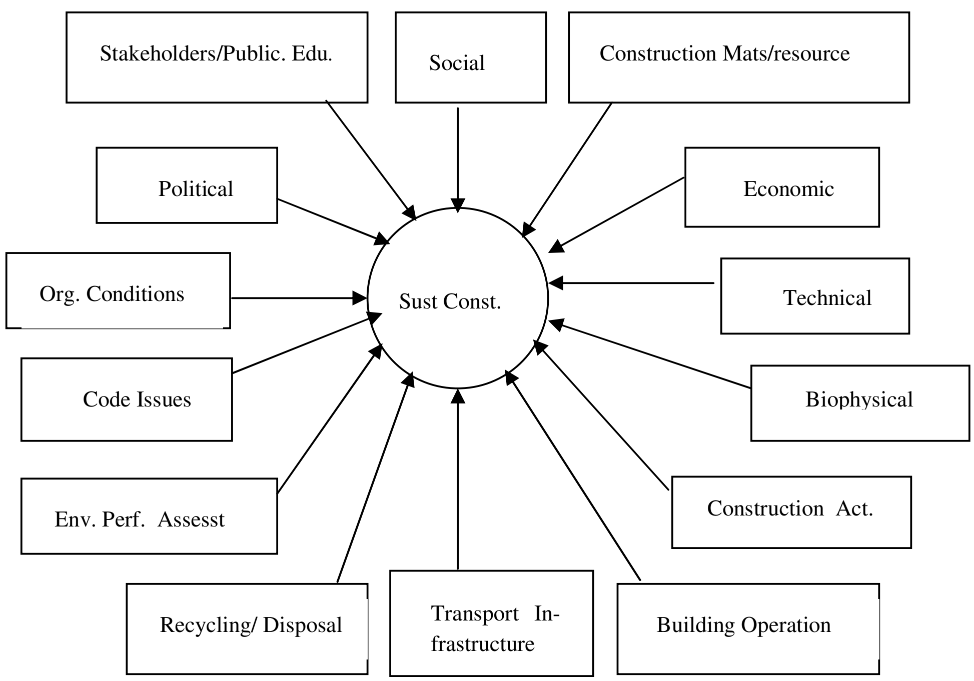

Figure 1. Dimensions of Sustainable Construction

2.1. *the criteria/ or sub-items/metrics*

All the documents above compiled various sub-items or criteria by which the identified indicators could be described or assessed. It is observed, however, that for the same indicator sited by two documents, there is little or no commonality at all among the list of sub-items/ factors. For example, While, Hill and Bowen (1997) list: Improve the quality of human life; Provide social self determination; cultural diversity in development planning; Provide, protect Human health (through a healthy and safe working environment); Implement skills training, enhance capacity (for the disadvantaged); Fair/equitable distribution of social costs of construction; Inter-generational equity –under social dimension, Howard (2000) lists: Decent and affordable Housing; Security; Education; Access to Transport; Education and Training for construction; Image of Construction; Working conditions in construction, under the same indicator i.e. social dimension.

In addition, there are cases where an item under one indicator (dimension) in a certain document appears to be an item in a different dimension. For example, affordability appears as an item under Social dimension in Howard (2000) but occurs under Economic dimension in Hill & Bowen (1997). Arbor (1999) centred on the various levels (Federal, state, Regional/City, Building owner, Lending Institution) as the sub-item under Economics, while Hill & Bowen (1997) on the other hand highlighted such items as employment, pricing, investments, choosing environmentally responsible contractors/ suppliers, competitiveness under economic sustainability; and in Howard (2000) work types, project size, work load fluctuation, country output of construction, structure of industry, and structure of sub-contracting in the industry were selected under the same perspective. Howard (2000) under Construction Material and Resources lists: resources, land, energy and CO2, minerals wood, Pollution, wastes from material production, waste uses as a construction material as contrasted with the 4 requirements of sustainable building materials (Augenbroe et al, 1998) mentioned in the previous section of this paper. Hill and Bowen (1997) placed: energy, materials, land, and pollution of land, air and water were items that emerged rather under the Biophysical dimension. Water, Noise, and Dust pollutions fell under Construction Activity dimension in the document of Howard (2000). The items of the other dimensions follows similar criss-crossed trend. This poses a difficult measurement problem.

Assessing the performance of sustainable construction will require a clearer definition of relevant indicators and their criteria (or metrics), even in the same country. The present situation shows a rather a non-focused approach towards attempting to assess sustainable construction. Unless a framework is established that identifies which indicators are relevant under which circumstance, assessing the performance of sustainable construction in regional or continental levels would be difficult, if not impossible; and even more difficult would be its management. And, the issue about performance management is: “if you cannot measure you cannot manage”. However, if these indicators and the factors are scientifically identified at local (national) levels, measurement would be more meaningful.

3. THE CLIENT AS AN IMPORTANT STAKEHOLDER

3.1. *clients and their projects.*

Construction firms are moving closer to their clients who are themselves becoming more sophisticated and are often now the driving force for improvements in the construction process (Yisa et al, 1996). Being the sole initiator and financier of construction projects the issue of sustainable construction should, thus, be seen and defined in relation to the client’s requirements. In particular, Latham (1994) maintains that clients “have a substantial role to play in setting demanding standards and insisting upon improvements”. Ultimately, he continued, they have the most to gain from ensuring the implementation of ‘best practice’.

The case of the Petronas Twin Towers of Malaysia is an example of a project in which the client knew what he wanted. Completed in 1996, the Petronas Twin Towers, standing at 452m in height and joined by a sky bridge at 41st and 42nd stories, needed to meet a lot of criteria to satisfy the Prime Minister, Dr.Mahathir Mohammed, the client. In addition to satisfying the technical requirements of cost, time and quality, it was expected to:

- Be a World Class building (Mahatmir, 1992)

- Put Koala Lumpur on the world map (KLCC Holdings Bhd., circa.1995:1)
- Incorporate local design features so as to create a recognizably Malaysian skyscraper. (Bunnell, 1999)
- It must represent the Islamic religion and geometric traditions (Cesar Pelli and Associates, 1997:29)
- It must convey a specific sense of their tropical location (Cesar Pelli and Associates, 1997:29); among others.

In such a situation, success in the perspective of the client means more than a mere completion of project.

Major clients are shaping the world with similar drives for "Mega Structures" e.g. such tall buildings as The Tapei 101 of Tapei (Taiwan, 509 m); Petronas Towers of Kualar Lumpur each); Sears Towers of Chicago (USA, 442). Such long bridges as the Akashi Kaikyo of Japan, 1991m; The Izmit Bay, Turkey, 1668m; The Humber, UK, 1410m etc. are undertaken to address social needs as well as other desires and ambitions of the clients. The trend is likely to continue so long as major clients see these structures as satisfying a nationalistic need. It is a whole new line of competition. The impacts or effects of these Mega structures, as well as the driving forces behind them, on sustainable construction become an important issue to address. This brings to focus the important role of the client in sustainable construction as an aspect of global sustainable development. This view is also supported in the document " Achieving Sustainability in Construction Procurement (2000)" produced by the Sustainability Action Group of the Government Construction Clients' Panel (GCCP). The document submits that "in the move towards sustainable construction, the clients of the construction industry have a key role". The proposition is that, clients should be given their usual role as promoters of construction – promoting sustainable construction.

3.2. *Clients' Ambition versus Sustainability concepts*

As to whether or not we need all of these monuments is an on-going debate. In the article: "the end of tall buildings" by Kunstler and Salingaros (2001) the authors predicted that the age of skyscrapers is at end. Following the publication, several comments have taken exception to this thought. However, from the point of view of sustainability, we need to ask whether all these mega structures that various ambitious clients around the world are building are supportive of or conflicting with Sustainability. Sustainable construction demands that projects satisfy economic, social, environmental, recycling & disposal, construction material etc. perspectives as well as those of the client's. Striking the balance between their ambitions and obsessions (as seen in their criteria), with sustainability issues defines the important role of clients in sustainable construction. Government as a major client of a country should initiate sustainable construction measurement and management by establishing the relevant indicators and factors as part of the national building codes.

4 PROPOSED FRAMEWORK FOR MEASURABLE SUSTAINABLE CONSTRUCTION.

The question that remains is whether sustainable construction should be considered at global, national, or regional levels. Which indicators are global in nature and which should be left for the local situation? Which sub-items or factors should be considered to be influencing which dimensions?

For a methodological approach to performance measurement and hence management of sustainable construction, the authors propose an approach that begins with the measurements of performance at national (local) level. This calls for the establishment of performance indicators relevant to local conditions. This then could be linked to other localities, then with other nationals, then globally, by way of benchmarking for improvements.

This approach will allow for localisation of performance indicators and factors.

In each region, it will help to identify similarities and differences between indicators and factors of the countries involved, then to continental and global levels. The framework at the local level is depicted in figure 2 below.

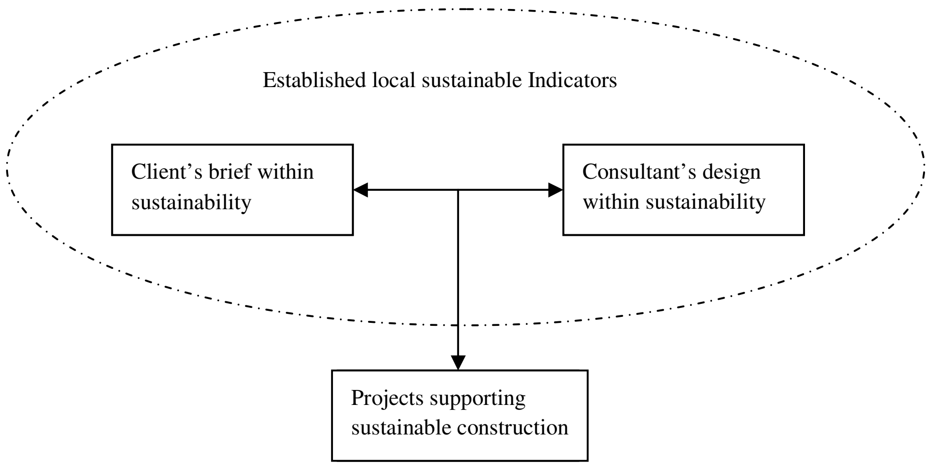

Figure 2. Framework for promoting sustainable construction.

In figure 2, the client brief should be considered within the framework of sustainable construction measures (or standards) prevailing in the locality. Once this is conceived, the consultants will also ensure that the brief is translated into a design that fits well within the sustainability framework. This will form the foundation on which a project that supports sustainable construction can be produced. This approach has the additional benefit of identifying common indicators across countries in the same region (selected as "regional measures"); then similar ones within a particular continent (selected as "continental measures"); and finally "global measures". With this arrangement sustainable construction could be measured, monitored, and of course managed, at the global, continental, regional, and national levels to take care of their respective perspectives and for different purposes.

In large countries like the US, India, China etc, it should be possible to expect sub-divisions within the countries. For example, in US, there is diversity of climatic zones from the north to the south, as well as varying traditional technologies from region to region, different legal requirements and varying building codes (Augenbroe and Pearce, 2000). This calls for different sets of sustainable construction indicators from state to state or from region to region within the same country.

4.1. *managing sustainable construction through performance measures***.**

Once the required performance indicators for sustainable construction with their factors are identified in a particular locality, it should then be possible to ensure a programme of sustainable construction through management. Performance monitoring and management of sustainable construction, beginning with the client at the project level provides the opportunity to address the issue at its very base. This may result in value judgement and decision making that will support sustainable development based on local, and indeed, international standards. As Plessis (2002) summarised: "sustainable construction industry no longer means simply that the industry is able to grow, but also that it supports the principles of sustainable development – which may mean that in some cases it needs to stop growing, or grow in different ways".
Figure 3 is a proposed flowchart showing the process of measuring and managing the implementation of a construction project within the framework of sustainability. The client's need of project is evaluated within the criteria of sustainable construction as contained in the codes of the country or locality. Based on the results of the interaction between the two, the client decides to proceed with the designs or stops the entire project, leaning on the consideration of sustainable construction and hence development.

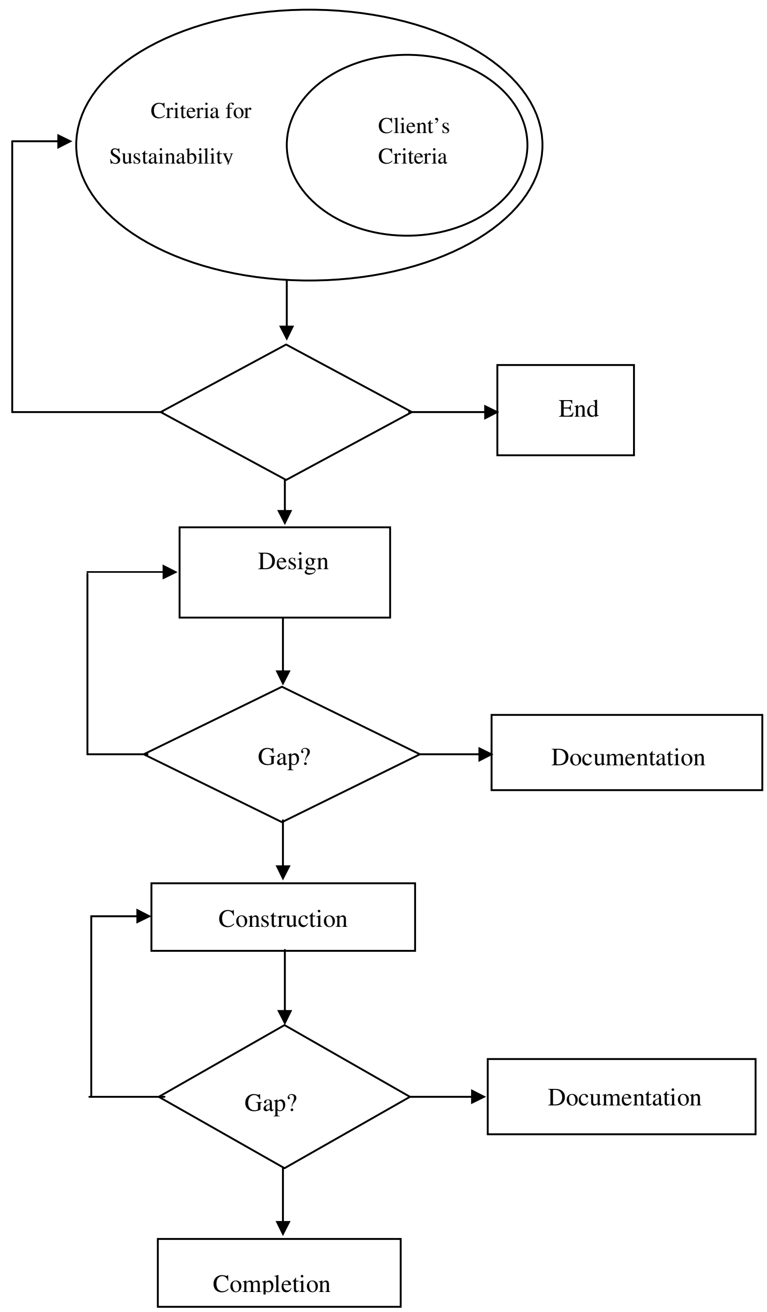

Figure 3. Sustainability Performance Management Process

At the design phase the sustainability test will continue to ensure that the design team is working within the framework of sustainability. The same applies to the construction phase. Wherever a gap is identified, correction is made (where possible) and should be well documented for future improvements.

5.0. CONCLUSION.

The concept of sustainable construction leads to sustainable construction industry. These are core aspects of sustainable development as a global agenda. In broad terms, society has come to realise that there is the need to ensure "social progress that meets the needs of the people, economic growth, effective protection of the environment, and efficient use of resources" (Howard, 2000). To achieve these objectives requires a methodical approach to identify, where we are, why we are here, where we want to go and how. It requires comprehensive management based on performance measurement of relevant indicators as they are identified in specific locality. Various countries, regions, and continents are at different levels of development and have different climatic, cultural, social settings. They are blessed with different resources. Sustainable construction issues, thus needs to begin at the local (country) level, and indeed, with projects. As it is with most issues on globalisation, it is proper to "think global, but "act local" first. Most importantly, the client, who is the mother of projects, should be recognised as an important player in promoting sustainable construction.

Reference:

Action Group of the Government Construction Client's Panel (GCCP). 2000. Achieving Sustainability in Construction Procurement. *Constructing the best Government Client.*

AggRegain. 2007. Sustainability in Construction. *The sustainable aggregates information service, "wrap"*.

Arbor, A., (1999). National Sustainable Buildings Workshop. University of Michigan. http://www.umich.edu/~nppcpub/workshops/indicators.PDF . Accessed 18/5/07

Augenbroe, G., Pearce, A.R., Guy, B., Kibert, C.J. 1998. Sustainable Construction in the United States Of America: A perspective to the year 2010".CIB-W82 Report June1998 http://www.p2pays.org/ref/14/13358.htm. Accessed 18/5/07

Augenbroe, G., Pearce, A.R., 1998. Sustainable Construction in the United States of America: A perspective to the year 2010.http://maven.gtri.gatech.edu/sfi/resources/pdf/CP/CP009.PDF.Accessed 18/5/07.

Bunnell, T. 1999. Views from above and below: The Petronas Twin Towers and/in Contesting Visions of Development in Contemporary Malaysia.

Brundtland, G (ed) 1987. *Our Common Future: The World Commission on Environmental and Development*. Oxford University Press.

Cesar Pelli and Associates 1997. Unique, unlike any Western Skyscraper, Concepts, March/April 28-31. Construction Related Sustainability Performance Indicators (Setting Targets & Monitoring "Real" Performance in the Sustainable Built Environment). Fundamental Matrix: 2010.

http://www.sustainable-design.ie/sustain/matrix.htm. Accessed 23/4/2007

Hill, R. C., Bowen, P.A. 1997. "Sustainable construction: principles and a framework for attainment. Construction Management and Economics, 15:3, 223-239

Howard, N., 2000. Sustainable Construction –the Data. Centre for Sustainable Construction. UK. http://projects.bre.co.uk/sustainable/SusConstructionData.pdf. Accessed 23/4/2007.

KLCC Holdings Sent. Bhd. (circa. 1995). Meeting Future Needs, Marketing Brochure.

Kunstler, J.H., Salingaros, N.A. 2001. "The end of Tall buildings". Planetizen, the Planning and Development Network. http://www.planetizen.com/node/27. Accessed 17/5/07

Latham, M. 1994. "Constructing the Team". London, HMSO.

Mahathir Mohamed (1992). Speech at the unveiling of the Kualar Lumpur City Centre Project , Selangor Turf Club, 15/9/92. www.jpm.my/about2htm

Plessis, C. D., (2002). Agenda 21 for Sustainable Construction in Developing Countries –A discussion document. http://www.buildnet.co.za/akani/2002/nov/agenda21.pdf

Walsh, C.J. 1998. European Charter on Sustainable Design & Construction. Forum on Sustainable Construction Region of Ireland.

Yisa, S.B., Ndekugri, I and Brian, A. (1995). "A Review of Changes in the UK Construction Industry. Their Implication for the Marketing of Construction Services". European Journal of Marketing. 30 (30) 47-64. MCB University Press.

Urban bioclimatic indicators for urban planers with the software tool *SOLENE*

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ABSTRACT: The interactions between a building and its nearby environment are numerous and complex enough to require serious means of investigation, more especially as the requests of the new regulations and those of the users become increasingly demanding. To make it easier to understand these interactions, one of the aim of the Cerma laboratory is to develop comprehensive methods of investigation and the complementary evaluation tools in such a way they can help to the architect and the urban planer in their decision making process. Such a research takes on its full meaning in this period of a renewed interest for the protection of the environment and sustainability. After a concise summary of the main principles behind the methods and the tool we present in this paper, we will describe some " indicators" through case studies that highlight the possibilities of the sofware, specially in case of urban investigations. The examples are choosen among various but recent studies that we achieved for architects, engineering departments or else the office of the urban development of our city.

1 INTRODUCTION

The growing need in urbanization and at the same time this renewed energy savings consciousness lead architect and urban planers to pay more and more and more attention to the relationship between the buildings and their nearby environment. But the lack of comprehensive methods and tools able to give reliable answers to the multiple constraints makes difficult the taking into account of the various parameters; many of these constraints are in contradiction, and even the intentions of the designer are real, functioning problems are too often noted, creating discomfort for the users and extra-costs (for example the problems with overheating, glare, poor natural light, etc., generally result in the addition of uncontrolled protection devices, costly air-conditioning systems, increase of electric light consumption, etc.)

This is why among the various topics of research of the Cerma laboratory, one of the most important relates to the development of suitable methods and tools, mainly based on numerical simulation. From the definition of some pertinent "morphological indicators" and their evaluation with our key software tool SOLENE, the urban planner and the architect is able to carry out investigations concerning the microclimatic and solar fittings of buildings and more generally urban forms. Smaller scales studies like the impact of solar protections or other devices such as porous screens can be also considered, even this paper focuses on urban analysis only.

The particular structure of this simulation tool consists of more than a hundred of small but specific operations that can be chained or combined, automatically or according to the user's needs ; thus it becomes quite easy to develop its own functions for a specific problem.

The visualization functions use the 3D graphics API Open Inventor™ and propose various ways of representation which outline the different behaviours observed in space and time, all of them with coloured maps over the faceted surfaces of the 3D model, as shown further in the examples. These functions can display various requests and calculations from the database that any simulation build – for example the user can display the values over a given threshold only, the difference between two simulations results on the same geometry, etc.

2 THE SOFTWARE TOOL SOLENE

Some previous papers (Miguet & Groleau, 2002, 2001) already gave a detailed description of the physical models and the various simulation procedures that are used in SOLENE. In this paper we will only summarize the main principles.

2.1 The geometrical model

The geometrical 3D model can be imported from any CAD software that uses the ACIS engine. In theory the model is not restricted in form or complexity, provided it is consistent enough. The model has to be meshed to perform most of the simulations, except for cast shadows; but even the whole model is taken into account in the process, the simulation itself can be performed on selected surfaces of the meshed model only; this is interesting both for reducing the heavy calculation and for vizualisation purposes (Figure 1).

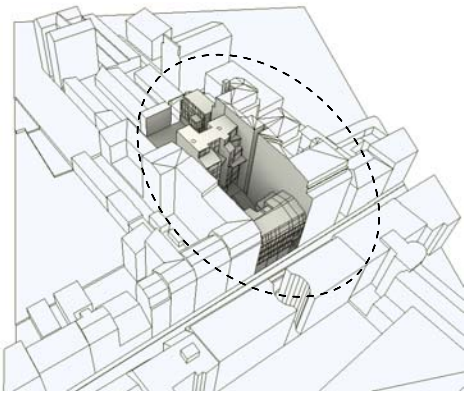

Figure 1. Simulation can be performed onto the surfaces selected by the user only; the levels of details for the object and the environment can be different.

2.2 Sun and sky models

Sun is modelled as a point source; its angular position is given by the celestial geometry and its energy is calculated from a statistical radiance model. The model of the sky vault is a hemisphere of infinite radius, with the scene to be simulated located at its center. This hemisphere can be seen as a source of diffuse energy with a non-uniform distribution (Fig. 2).

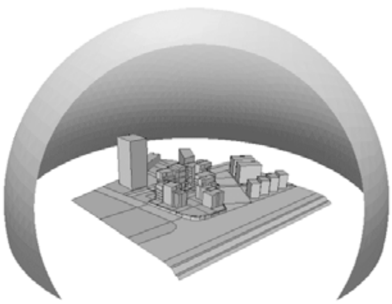

Figure 2. The urban scene under an overcast sky (the sky small radius is for visualization purpose only).

For simulation purposes it is meshed with a geodesic triangulation, and the luminance values that are mapped on the hemisphere come from the well-known “all weather” Perez model. So

SOLENE can deal with every kind of statistical distribution, from dark overcast to bright clear sky, with or without sun.

2.3 Gathering the energy onto the urban scene

Radiance or luminance values are collected on every patch of the studied scene; irradiance is calculated directly, but the illuminance of the environment is obtained from an integration over the luminance distribution over the whole hemisphere. From irradiance values we get illuminances through the light efficacy model proposed by Perez again.

2.4 Energy exchanges (radiosity)

The previous process has brought energy to the surfaces facing sun or/and sky only. But many surfaces of the environment (mostly inside surfaces such as a ceiling) are not directly exposed. They receive energy by reflection from other surfaces, according to their reflection factor. This is now a classical radiative transfer problem which is solved in SOLENE with a radiosity algorithm. The solution is calculated by the “progressive refinement” method due to Cohen.

It must be noted that the computation of the solution needs form factors, that is to say the geometric relationships between all the patches of the meshed scene. They express the intensity of the energetic exchanges between surfaces. In computer graphics these are usually computed “on the fly”, while in SOLENE they are calculated first and stored on disk.

This method allows to display the form factor sum for every patch of the scene (Fig. 3); it points out the zones of main exchanges of energy, and so gives useful information for the choice of materials, textures or colors (*i. e.* the zones for which the reflection factor might be increased to get the light deeper in a room).

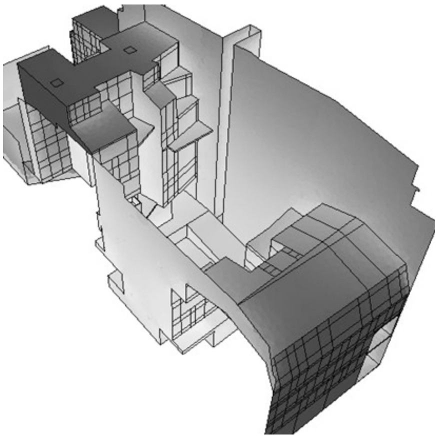

Figure 3. Display of the form factors: in light colour the zones of which it should be interesting to increase the reflection factor to obtain more light in this small urban courtyard.

2.5 The user interface (GUI)

Most of the functions are accessible via a graphic interface which is divided in three main areas (Figure 4), while other ones need a command line:

- The display window where the user can zoom, move and rotate the model ; he can also select a face and get various information about it.
- The left window lists all the geometries; only the highlighted ones are displayed. The geometry must be selected to carry out the simulations.
- The menu bar makes it possible to define the characteristics of the project (latitude, material properties, sun and sky conditions, etc.); it operates various operations with the geometries, and launch the simulation processes on the selected geometry.

3 MORPHOLOGICAL URBAN INDICATORS

3.1 The leading ideas

The analysis of a building or a urban space in terms of energy savings and comfort needs a multicriteria approach. That means that several physical parameters must be studied simultaneously. But even though the interaction between the constructions and their environment depends on physical parameters, the effects on the users and the power consumption can vary in an important way according to the use of the construction: a residential building, a commercial vocation area, a building for business activity only, or these various functions mixed all together lead to very different constraints. So we will pay particular attention to the connection between the physical approach and the intention of use of the constructions.

For building and urban analysis, we have developed specific indicators that focus on the morphology (density, compactness, heat losses and gains), the exposure to sunlight radiation (duration of sunshine and energy), the potentiality in natural light (daylight access and occultation), but also questions of visibility (areas seen from a particular point), etc. Comparison between various proposals can be carried out, and the impact of a specific modification easily highlighted.

These indicators have been built from a theoretical knowledge and multiple expert analysis that finally have lead us to think about "parameters" that could bring some reliable information about the project confronted with its environment. On the face of it these indicators are based on physical investigations, but there is no obstacle to introduce in SOLENE files with "social" or "economical" data, such as a number of inhabitants, a cost of hiring, etc., just like a SIG.

3.2 The indicators: interpretation and limits

The interpretation of these indicators must be careful and made with proper judgment; as said before, they allow interesting comparisons between different propositions, but they are not intended to give rules or provide typical organization of any kind, no more than they carry any normative idea. For a specific indicator, a good value for a given season can be bad for another; or two of them may lead to contradictory architectural solutions; there's nothing surprising about that, it simply corresponds to the real nature of the building complexity in the face of its climatic environment.

The different indicators proposed in this paper do not constitute a limited and closed list. At the moment we are working on new indicators for the characterization of the risks of glare. In fact they must fit to the objectives pursued and they have to be build on demand. Their interpretation is heavily related to the function of the behind spaces (offices, apartments, facilities…).

The numerical estimate of these different indicators requires a 3D model, as usual in SOLENE; most of them can be calculated directly with the built-in functions of the software tool. The model can be very basic (gauges only for studying urban dispositions at the scale of a block), or more detailed according to the scale of the objects that are being studied (until the small mesh size of filter devices such as meshed metal screens – this specific implementation is not presented in this paper, see (Miguet F. 2007) for more details).

4 APPLICATION TO MULTICRITERIA URBAN ANALYSIS

Among the many possible indicators, we describe in the following some of them used in recent urban analysis carried out in Nantes. Those presented here can be considered as rather general and they can be used for almost any kind of urban analysis, even we have developed other ones for specific investigations.

4.1 Urban built density

The urban built density indicator D_{surf} is the ratio between the ground occupation and the whole area of the project location. The more important is D_{surf}, the more natural soil is neutralized (with a significant reduction in water infiltration for example). The cubic density D_{vol} can be defined as the ratio between the built volume and the area of the urban territory; it's a kind of average height of the buildings, and it is expressed in meters.

These two indicators are closely related to surface optimization, the profitability of public services and equipments, the importance of mineralized or vegetalized areas. They are also related to economical aspects because they concern the consumption of the costly urban space and also the complexity of the urban distribution networks. The implementation of these indicators to social aspects can concern the concentration of the residents for example.

In a more precise approach, the previous indicators should be completed by other ones related to the handling of the public spaces (mineral, vegetal, water, etc.),.

4.2 Compactness

The compactness C estimates the ratio between the exchange areas of the envelope and the floor area; the envelope includes walls, ground and roof. The minus C is the more compact is the building. A more precise approach is to split C into two parts: C_1 for the exchange areas of ground and roof, C_2 for the walls only, with $C = C_1 + C_2$. C_1 reduces with the number of floors and C_2 is related to the shape of the building, as shown on the different configurations of Fig. 4.

This indicator have a serious impact on heat losses and solar benefits in the cold season, and risks of overheating in the hot season; it can also affect construction costs and maintenance expenses (for a given volume, the more compact the building the less the area of the envelope).

In winter C should be minimized to avoid heat losses, even it allows heat gains at the same time; usually losses are more important than gains, but it depends also on the outside average temperature, on the importance of the sunny periods and the ratio glazed/non glazed façade.

In summer a low value of C should be interesting to avoid too much heat gains; again keep in mind that with this indicator the idea is not to recommend uniform cubic blocks, but it can be used to compare different configurations and alert about a heavy difference in operating costs.

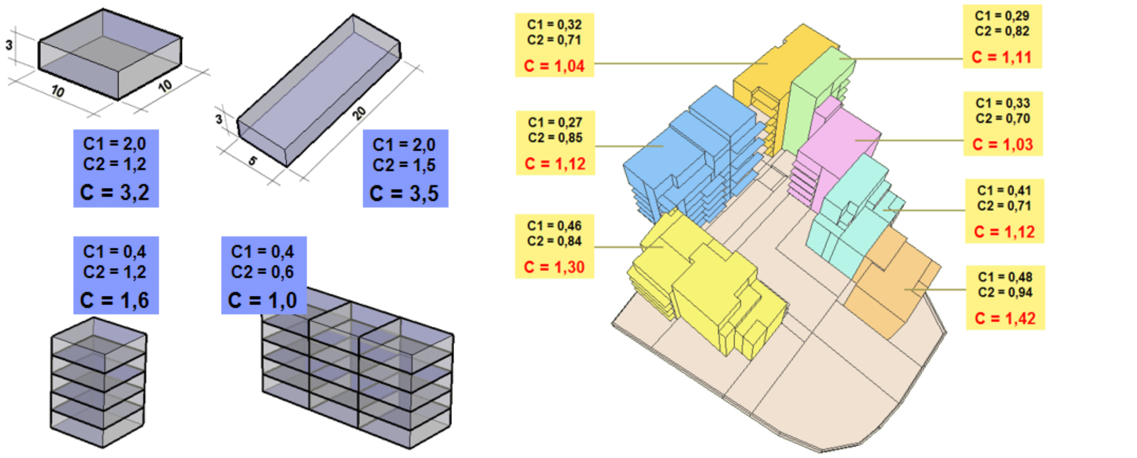

Figure 4. The building shape and the number of floors have a great influence on the compactness C (theoretical approach on the left). Values of compactness calculated on a new urban development in Nantes (application example on the right).

4.3 Orientation of the façades

It's well known that some orientations are critical, especially south and west facing façades for the hot season in our countries. For our latitudes we will use mainly the south and the west facing indicators, but other orientations might be more pertinent in case of different latitudes and climatic environment, or for specific applications: for example the percentage of the north facing façades would give an idea of the heat losses that cannot be balanced, or the indoor spaces that benefit from constant quality light (Figure 5).

The south facing indicator O_{sud} expresses the percentage of façades facing south; it has to be maximized during the cold and the middle season to make the heat gains easier. In summer the south façades are not so critical because they don't receive the highest energy due to the solar height, and openings can be easily protected (balcony, overhang, etc.).

The problem is different with the west facing indicator O_{ouest} (% of façades facing west) that expresses, for mid-range latitudes, a risk of summer discomfort (overheating and glare); it points out the necessity of architectural dispositions, or a specific typology of façade, or a reorganization of the functions to avoid discomfort and heavy charges for cold production in the hot season, especially in case of business spaces.

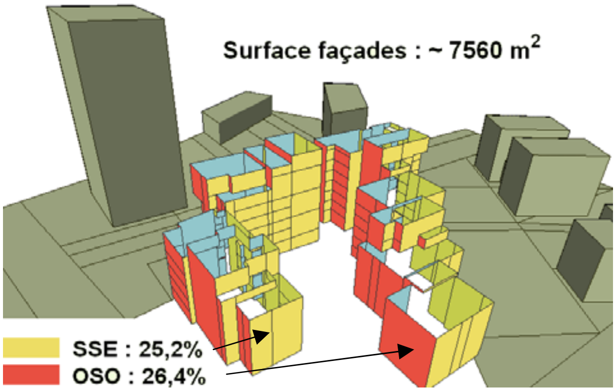

Figure 5. Display of the percentage of façade in a given orientation (south and west here).

4.4 Solar gains of façades related to floor area

The indicator S_{floor} is defined as the average of the daily direct solar energy related to the floor area (unit: Wh/m^2). When comparing different solutions, it is particularly interesting to refer to the floor area unit as this is the usual reference for any type of urban planning or construction. Building costs, sales price, consumptions, taxes, etc. are generally calculated referring to 1 m^2 of floor. The calculation of this indicator refers to the compactness C_2 indicator (see 4.2)

It has to be maximized in winter and at the middle season as it represents a solar heat gain; on the other hand, it has to be minimized in summer unless this free energy might be used for other saving purposes (production of electricity with photovoltaic for example).

This indicator should be more precise if taking into account the diffuse energy reflected by the ground and the nearby façades, as well as the solar factor of the windows.

4.5 Potentialities in natural light

The indicator P_{light} is related to the area of sky that is visible from any point of the environment. In other words, the more sky you see the more light you get. This area results greatly from the building morphology itself (Figure 6), but also from the nearby environment: masks due to other buildings, trees, etc. can reduce drastically the availability in natural light. On the other hand P_{light} is totally independent of the orientation of the façade in case of an overcast sky.

This indicator has to be evaluated on the façades of course, but it is also interesting for the outside spaces, for example to specify the site for a public equipment such as a kindergarten.

Except in case of specific purposes, this indicator has to be maximized in order to benefit from the natural light and reduce the electric consumption for the behind spaces.

In the above the indicator has been evaluated regardless of the building materials, and their reflection factor is not taken into account; however a sunny light façade reflects a lot of light, and so this indicator should be weighted by the reflection factor of the different materials (taking into account both color and texture). The radiosity implementation in Solene makes this evaluation possible, and more a comparison between the two configurations (before and after reflections) can highlight the impact of the materials and so help in their choice (see Miguet, F. & Groleau, D. 2002 for more details). The display of the form factors gives also precious indications about the relative importance of the different surfaces in the reflection process.

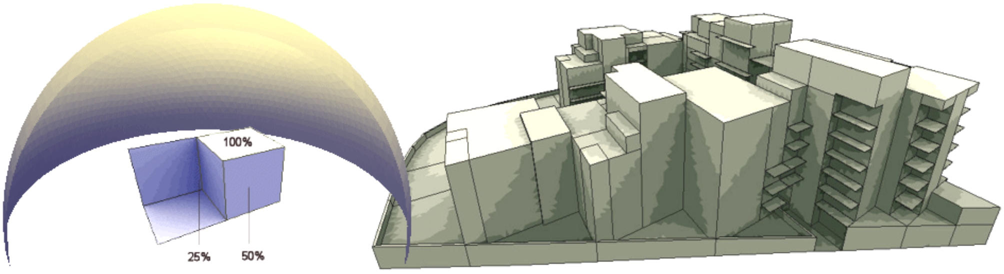

Figure 6. Theoretical availability (%) of natural light on a terrace, a vertical wall and a concave corner (left). Application to buildings with concave angles; display by 10% bandwidth (right).

4.6 Losses due to the urban masks

This indicator is particularly interesting to compare different urban dispositions because it highlights the effects of the urban masks on two important parameters: the solar heat gains and the potentialities in natural light. It is calculated as the ratio between the solar flux (respectively the natural light) received by the façades with the urban environment masks and this same solar flux (resp. light) without masks. The smaller the indicator the more the urban masks penalize the solar or sky resource.

4.6.1 *Solar losses*

In winter this indicator has to be maximized to get the maximum of heat gain; the same at the middle season because low outside temperatures can be mostly offset by solar gains. In summer it should rather be minimized to avoid solar contribution. The indicator can also be interpreted as a pointer to the consequences of specific urban dispositions: for example the west facing façades that show a mask effect in summer, or the south facing façades with a regrettable mask effect in winter, etc. We sometimes used it as a deciding factor in case of bone of contention about solar rights.

4.6.2 *Light losses*

Same as before, the indicator has to be maximized to get the maximum of light during the cold and the middle season with overcast skies, but minimized during summer. Light losses on a north facing façade due to a urban mask can be weighted with the reflection factor of the opposite façade, *i.e.* the south one of the mask (Figure 7).

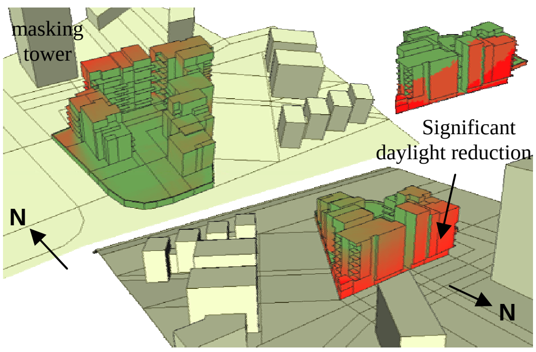

Figure 7. The more red colour the more is the reduction of daylight due to the surrounding buildings; here the tower causes an important loss in natural light for these north-facing apartments (~ 20%).

4.7 Visibility

The visibility is something different from the above; the previous indicators were clearly related to sustainability and comfort, while visibility may concern the inhabitant comfort only.

Nevertheless this indicator is important in urban planning because it can highlight some “visual pollution” due to a new project, or on the contrary the benefit of a protected view to a specific point of interest (monument, river, etc.). Other classical applications include the cartography of the visibility area of a field of aerogenerators in the countryside, etc.

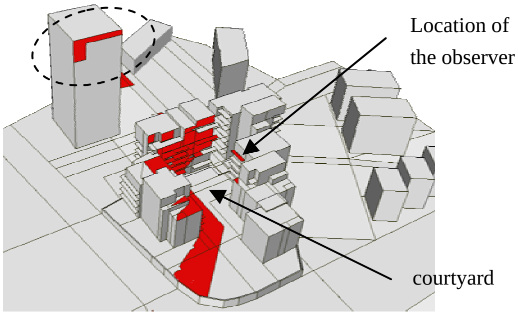

Figure 8. From his balcony, the observer sees only a very small part of the nearby tower; the inner courtyard is visually protected from the tower.

5 CONCLUSION

The goal of this paper was to highlight how some urban indicators, calculated with the 3D simulation tool SOLENE, can significantly help the architect or the urban planner in their decision process. The simulations give them important and reliable information about the close connections between the buildings and their environment.

On the other hand it's important to keep in mind that these indicators will not give any ready-made solution; the decision-maker has to compromise with many constraints. These are more or less difficult to manage, and the objective and practical elements given by the simulations results will be reliable deciding factor for the final choice.

Finally, the possible uses of our tool are not limited to the applications that have been described here. Its open structure makes easier the development of new functions, and makes it attractive from an educational point of view. It helps the user to understand the mechanism of the interactions between the various parameters; this is the reason why we use SOLENE in the teaching process with the master students of the school of architecture of Nantes for their project adjustments.

6 REFERENCES

Cohen, M. F. & Wallace, J. R. 1993. Radiosity and Realistic Image Synthesis, *Academic Press*.
Miguet, F. 2007. A further step in environment and bioclimatic analysis: the software tool Solene, *IBPSA 2007*, Beijing, sept. 3-6, 2007.
Miguet, F. & Groleau, D. 2002. A daylight simulation tool for urban and architectural spaces - Application to transmitted direct and diffuse light through glazing, *Building and Environment*, Volume 37, Issues 8-9: 833-843, August-September 2002.
Miguet, F. & Groleau, D. 2001. A daylight simulation including transmitted direct and diffuse light. Application to the evaluation of daylighting inside glazed intermediate spaces, *IBPSA 2001 proceedings, Rio de Janeiro, Brazil*: 907-914.
Miguet, F. & Groleau, D. 1998. SOLENE et la simulation des éclairements directs et diffus des projets architecturaux et urbains , *IBPSA France, Sophia Antipolis*.
Perez, R., Seals, R. & Michalsky, J. 1993. An all-Weather Model for Sky Luminance Distribution, *Solar Energy* 50(3): 235-245.
Sillion, F. X. & Puech, C. 1994 "Radiosity and Global Illumination," Morgan Kaufman, San Mateo (CA, USA).
Tregenza, P. R., Michalsky, J. J., Perez, R. & Seals, R. 1991. Guide to recommended practice of daylight measurement, *Report of CIE Technical Committee 3.07,* 8th Draft, Departement of Architecture, University of Adélaïde.

Perspectives of building sustainability assessment

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ABSTRACT: The concept of sustainable building is usually related to environmental characteristics although the social, economic and cultural indicators are of substantial importance. Any building level assessment method is complex and involves contradictory aspects; emphasizing the qualitative criteria only increases confusion. The R&D and standardization is thus concentrated to transparency and usability of the environmental methods. Other directions of research are aiming at performance-based design and methods to take regional and cultural aspects into account. In this paper, the perspectives of the sustainability assessment of a whole building are presented based on the state-of-the art, feasibility study on performance analysis and development of extended LCA for buildings. Based on the case studies of building sustainability assessment using various tools, the environmental indicators were shown to be often of lesser importance than the other, soft ones. At the end, will be presented and discussed the first steps in the development of a building sustainability assessment method for Portuguese residential buildings.

1 INTRODUCTION

A building project can be regarded as sustainable only when all the various dimensions of sustainability –environmental, economic, social and cultural ones - are dealt with. The various sustainability issues are interwoven, and the interaction of a building and its surroundings is also important. The environmental issues are in common those which cope with reducing use of non-renewable materials and water, and reducing emissions, waste and pollutants. The following goals for an overall assessment can be found in several agendas: optimization of site potential, preservation of regional and cultural identity, minimization of energy consumption, protection and conservation of water resources, use of environmentally friendly materials and products, healthy and convenient indoor climate and optimized operational and maintenance practices.

The purpose of sustainability assessments is to gather and report information for decision-making during different phases of construction, design and use of a building. The sustainability scores or profiles based on indicators result from a process in which the relevant phenomena are identified, analyzed and valued. Two extreme trends can be recognised at the moment: on one hand, complexity and diversity of indicators of different operators and on the other hand, evolution towards better usability through common understanding and simplicity.

Development of assessment methods and respective tools is a challenge both for the academia and practice. A major issue is that of managing the flows of information and knowledge between the various levels of indicator systems. A variety of sustainability assessment tools is available on the construction market, and they are widely used in environmental product declarations like e.g. BREEAM in the U.K. and LEED in the U.S. (Edwards & Bennett 2003). There are also LCA-based tools available that are especially developed to address the building as whole, like e.g. Eco-Quantum (Netherlands), EcoEffect (Sweden), ENVEST (U.K.), BEES (U.S.), ATHENA (Canada) and LCA House (Finland). A comparison of contextual and methodological aspects of tools has been made e.g. by Forsberg and Malmborg (2004). The majority of the tools is developed based on a bottom up approach, i.e. a combination of building materials and components sums up to a building, and this even though they are designed to consider the whole building including energy demand, etc (Erlandsson & Borg 2003). Tools to support decision-making in accordance with principles of performance based design have also been developed, mainly in research communities.

The assessment tools, either environmental or performance-based are under a constant evolution in order to overcome their various limitations. The main goal, at the moment, is to develop and implement a systematic methodology that supports design process of a building. The methodology should result to the most appropriate balance between the different sustainability dimensions, and be practical, transparent and flexible at the same time. It should be easily adaptable to the different kinds of buildings and to the constant technology evolution.

In this paper, approaches to incorporate the three sustainability dimensions within a building project are presented and discussed based on a feasibility study and state-of-the-art. In a more thorough way, the sustainability is dealt with the concepts of eco-efficiency and cost-efficiency that result from a holistic building performance analysis. Then, the potential to introduce the building's economic and social impacts ("soft indicators") in the originally environmental LCA methodology is studied, and the new developments and perspectives for the Building Sustainability Assessment (BSA) using global indicators is presented.

2 APPROACHES TO BUILDING SUSTAINABILITY

2.1 *Sustainability indicators of a building project*

The sustainability indicators of the construction and real estate sector give information about the influences of the industry as a whole and about the impacts of construction and operation of buildings and other built assets. Different approaches for indicators exist due to differences between societies, industrial traditions, environment and geography.

The sustainability indicators for a building project can be selected from various lists prepared at governmental, sectoral and community level. The Agenda 21 by CIB (1999) states that the framework of relevant issue areas should be based on the assumption that a sustainable building approach includes all factors that may affect the natural environment or human health. For a contactor or facility manager, it is important to differentiate between the criteria and tools used to assess technology at the generic or global level, and the approach used at the site specific application or local level (Environmentally Sound Technologies 2003). In spite of some differences between the lists of indicators, most of them deals directly or indirectly with the following issues: resources consumption, environmental pressure, energy and water efficiency, indoor air quality, comfort and life cycle costs.

An indicator is expressed by a value derived from a combination of various measurable parameters (variables). Indicators have to be defined in a clear, transparent, unambiguous and correct way, even before the concern whether they relate and evaluate several parameters. The indicators are usually grouped (aggregated, categorized), and further various aggregated indicators may create subgroups in a hierarchical system.

2.2 *Managing and assessing building sustainability*

Building Sustainability Assessment (BSA) methods can be oriented to different scale analysis: building material, building product, construction element, independent zone, building and neighbourhood. Analysing the scope of the most important sustainability support and assessment systems and tools it is possible to distinguish three types:

- Systems to manage building performance (Performance Based Design);
- Life-cycle assessment (LCA) systems;
- Sustainable building rating and certification systems.

i) Managing building performance

Performance Based Building is an approach to building-related processes, products and services with a focus on the required outcomes (the 'end'). This approach would allow for any design solution (the 'means') which can be shown to meet design objectives (Koukkari, 2005).

The comprehensive implementation of the performance approach is dependent on further advancement in the following three key areas: the description of appropriate building performance requirements; methods for delivering the required performance; methods for verifying that the required performance has been achieved.

The main purpose for a generic hierarchical model is to provide a common platform to define the desired qualities of a building and to develop a common language for different disciplines as well as to serve as a basis for development of design and technical solutions. The choice of the objectives in the hierarchical presentation shows also to some extent the values of the developer.

Based on the hierarchy of performance objectives and their targeted qualities, alternate design and technical solutions can be developed. The capability of different solutions to fulfil the performance criteria can be studied with verification methods. Figure 1 represents a generic model of building's performance analysis. Similar hierarchies are introduced by several organisations.

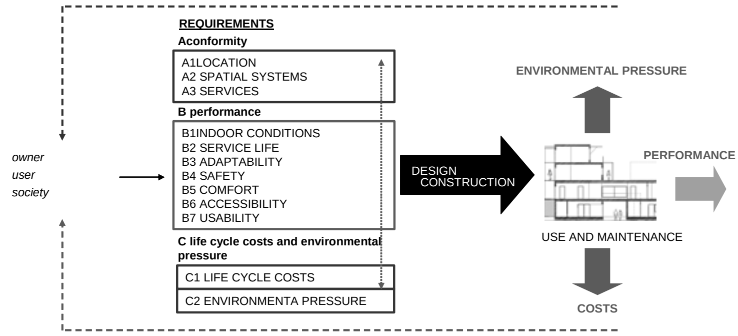

Figure 1. Example of a generic model of building's performance analysis (VTT ProP®).

This kind of method is providing some important benefits to both end users and to the other participants in the building process, since it promotes substantial improvements in the overall performance of the building, encourages the use of construction solutions that better fit the use of the building and promotes a better understanding and communication of client and users requirements.

Tools to support decision-making in accordance with principles of performance based design have been developed mainly in research communities. An example is the EcoProp software (Finland).

ii) Integrated Life-Cycle-Analysis of buildings

The complete building sustainability assessment (BSA) comprise the ways in which built structures and facilities are procured and erected, used and operated, maintained and repaired, modernised and rehabilitated, and finally dismantled and demolished or reused and recycled. Adoption of environmental LCA in buildings and works is a complex and tedious task as a building incorporates hundreds and thousands of individual products and in a construction project there might be tens of companies involved. Further, the expected life cycle of a building is exceptionally long, tens or hundreds of years.

The life-cycle of a building project starts before any physical construction activities and ends after its usable life. Figure 2 shows an integrated LCA of the building stages.

In the first LCA methods the concept of sustainable construction was confused with the concept "low environmental impact construction", therefore they failed to enter the mainstream sustainable development discourse. More recent LCA methods include the economic performance analysis in the evaluation. The economic assessment is an important factor in the success of any new approach in construction, to include sustainable principles. Demand for sustainable construction is influenced by buyer perception of the first costs versus life cycle costs of sustainable alternatives (Kibert, 2003).

The life-cycle inventory analysis (LCI) can be extremely complex and may involve dozen of individual unit processes in a supply chain (e.g., the extraction of raw resources, various primary and secondary production processes, transportation, among others) as well hundreds of tracked substances. The more rigorous the LCA methods are the more data intensive they are, therefore the assessment process can involve enormous expenses of collecting data and keeping it updated, particularly in a period of considerable changes in materials manufacturing processes. Some data needed for the LCA is expensive and difficult to obtain, and is most often kept confidential by those manufactures that do undertake the studies. According to Pushkar, Becker and Katz (2005), the databases do not include all the needed information for many of the relevant building products and components, nor the construction process itself. Therefore they conclude that LCA tools that editing of existing variables and adding new ones according to local conditions, is essential.

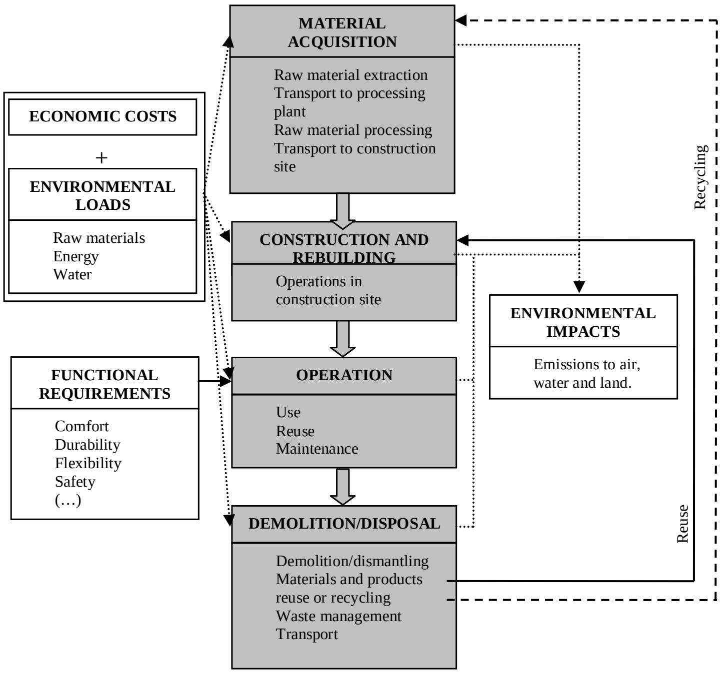

Figure 2.Integrated LCA of the building stages.

The goal of some BSA methods is to simplify the LCA for practical use. The simplified LCA methods that currently exist aren't comprehensive or consistently LCA-based but they play an important role in turning the buildings more sustainable. More accurate BSA tools will integrate environmental assessment, life cycle costs and methods needed to verify if the required performance has been achieved. LCA-based methods are used to compare solutions to help decide which solution corresponds to the best compromise among the different sustainability dimensions.

2.3 *Sustainable building rating and certification*

The rating and certification systems and tools are intended to foster more sustainable building design, construction, operation, maintenance and disassembly/deconstruction by promoting and making possible a better integration of environment, societal, functional and cost concerns with other traditional decision criteria.

These systems and tools can be used both to support the sustainable design, since they transform the sustainable goal into specific performance objectives and to evaluate the overall performance. There are different perspectives in different sustainable building rating and certification, but they have certain points in common. In general, these systems and tools, deal in one way or another with the same categories of building design and life cycle performance: site, water, energy, materials and indoor environment.

Near all of the sustainable building rating and certification methods are based in local regulations or standards and in local conventional building solutions. The weigh of each parameter and indicator in the evaluation is predefined according to local socio-cultural, environmental and economic reality. Therefore the major part of them can only have reflexes at local or regional scales. However, there are some few examples of global scale methods. This kind of methods are above all used at the academic level since the requisite reference cases have to be constructed and separately assessed for each building type which is a time consuming and expensive process.

There are three major building rating and certification systems that provide the basis for the other approaches used throughout the world: Building Research Establishment Environmental Assessment Method (BREEAM), developed in U.K.; Sustainable Building Challenge Framework (SBTool), developed by the collaborative work of 20 countries; Leadership in Energy and Environmental design (LEED), developed in U.S.A..

3 DEVELOPMENT OF BUILDING SUSTAINABILITY ASSESSEMENT

3.1 *Scope of the work*

The Portuguese building technologies and the indoor environment quality standards are quite different from most European countries. The first situation is mainly related to the fact that Portugal was not involved in the II World while the second is related to the mild climate. This reality normally hinders the use of foreign decision support and sustainability assessment methodologies without prior adaptation of the list of parameters, weights and almost all benchmarks. Another important reason that is clogging the real implementation of the sustainable assessment is the huge amount of parameters that project teams have to deal with: many of the methodologies presented in the sections above embrace hundreds of parameters, most of them not standard in Portugal and difficult to deal with for many project teams.

This study intends to be the basis for the future development of an advanced residential building sustainability rating tool, especially to be suitable in Portuguese traditions, climate, society and national standards. The research aims to cope with the mentioned problems and to real implement building sustainability assessment in Portugal. The name of the methodology that is under development is Methodology for the Relative Sustainability Assessment of Residential Buildings (MARS-ER from the Portuguese acronym).

In this section, steps to establish the methodology are presented. The indicators inside each sustainable dimension and their associated parameters will be presented. Additional it will be discussed how to calculate the weights, based in the local environmental, socio-economic and legal reality and in the type of building that is going to be evaluated.

First of all, system boundaries are presented. Then, the approach can be divided in four major stages: selection of indicators and parameters, quantification of parameters, normalization and aggregation of parameters and representation and the global assessment of a project.

3.2 *System boundaries*

At a fist stage, the methodology is being developed to assess residential buildings. Most of the Portuguese construction market is related with the residential sector and therefore the development of a methodology to support and rate this sector’s sustainability is a priority.

The object of assessment is the building, including its foundations and external works within the area of the building site. The impacts of the building in the surroundings and in urban environment won’t be assessed. Some authors concluded that restricted scales of study (corresponding for a single building for example) are too limited to take into account sustainable development objectives correctly (Bussemey-Buhe, 1997). Although, sustainable urban planning is normally limited to municipalities and regional authorities, therefore, it is more rational and straightforward to limit the physical system boundary to the building itself (or part of it) together with the site. This way, the methodology excludes construction works outside of the site location and construction of the different networks for communication, energy and transportation outside of the site location.

The temporal methodology's boundary should represent the whole life cycle stages of the building. In a new building it will consider all life-cycle stages, from construction to final disposal and in existing buildings the temporal boundary will start from the moment of the intervention to the final disposal. Besides the time boundary two other important aspects to define are the hours of normal occupation and use and the occupation density.

3.3 *Selection of indicators and parameters*

After defining the methodology's time and physical boundaries the next step is to choose the indicators and related parameters within the three sustainable development dimensions that are going to be used to assess the objectives of a project. According to Kurtz *et al* (2001) a parameters is a sign or a signal that relay a complex message, from potentially numerous sources, in a simple and useful manner. Therefore the main three objectives of the parameters are: simplification, quantification and communication (Geissler, 2001). Categories and related parameters are the basis of the methodology, since objectives and results will be conditioned by them.

Figure 3 resumes the parameters that are considered in the methodology under development. Other parameters could be included in further phases of development.

Assessment Objectives

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Indicators and Parameters to Assess

↓

Environmental Performance	**Societal Performance**	**Economic Performance**
• **Climate change:** Global warming potential. • **Emissions to air, water and soil:** Destruct. of the stratospheric ozone layer; Acidification potential; Eutrophication potential; Formation of ground-level ozone; Inert waste to disposal Hazardous waste to disposal • **Water efficiency:** Potable water use; Rain water use. • **Resources depletion:** Land use; Materials resource depletion; Fossil fuel depletion potential.	• **Hydrothermal comfort:** Relative humidity; Winter thermal performance; Summer thermal performance; • **Indoor air quality:** Air suspension solid particles; Carbon monoxide; Carbon dioxide; Ozone; Formaldehyde; Organic volatile compounds. • **Acoustic comfort:** Airborne sound insulation; Impact sound insulation; Reverberation time. • **Visual comfort:** Natural lighting use; Illuminances.	• **Life-cycle costs:** Costs before use of the building; Maintenance costs; Operation costs; Costs after building use; Residual value.

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Integrated Building Performance Analysis

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Representation and Global Index

Figure 3. Indicators and related parameters considered in the MARS-ER tool.

In the evaluation of the environmental performance it is necessary to analyse the potential effects related not only with the building materials or products but also with the operation of the building. For example, the assessment of fossil fuel depletion for a building's life cycle is based in its materials or products embodied energy (energy invested in extraction, transport, manufacture and installation), plus the operational energy needed to run the building over its lifetime.

The definition of the environmental indicators and parameters is based in the work that is being carried out in CEN/TC 350 WG1. The methodology uses the same indicators and parameters that the experts found relevant in the building environmental performance assessment.

In societal performance assessment, the methodology only considers the parameters related to the health and comfort performance of buildings during their use and operation. The methodology doesn't considers parameters that could raise some kind of complexity and subjectivity in the assessment, in order to facilitate its use and understanding by all Portuguese construction market's actors. The list of societal parameters presented in Figure 1 reflects the functional requirements of a residential building, according to national construction codes.

The economic performance parameters were defined in order to include all costs related to building's life-cycle, from cradle to grave. The economical performance analysis is not complete unless the residual value is evaluated. The residual value of a system (or component) is its remaining value at the end of the study period, or at the time it is replaced during the study period.

3.4 *Quantification of parameters*

After selecting the parameters it is necessary to proceed with their quantification. Quantification it is essential to compare different solutions, aggregate parameters and to accurate assess the solution. The quantification method should be anticipated. There are several quantification methods: previous studies results, simulation tools, expert's opinions, databases processing, etc. (Cherqui, 2004).

At the level of the quantification of the environmental parameters, there are some aspects to overcome, mainly in which regards to the availability of fundamental local LCI environmental data for all construction materials and products used in buildings. While there isn't local LCI it is possible to use the information given in Environmental Products Declarations (EPD's), and other LCI databases from nearby countries. MARS-RE recommends the use of the Central Europe's LCI data collected by Berge (Berge 2000). Another way is to use an external life-cycle assessment (LCA) tool to quantify the environmental parameters.

After quantifying the economic parameters listed in Figure 3, the next step is to calculate the sum of the total net present value (NPV) of the different costs. Therefore in the assessment there will be just one economic parameter: life-cycle costs.

3.5 *Normalization of parameters and aggregation*

The objective of the normalization of parameters is to avoid the scale effects in the aggregation of parameters inside each indicator and to solve the problem that some parameters are of the type "higher is better" and others "lower is better". Normalization is done using the Diaz-Balteiro *et al.* (2004) Equation 1.

$$\overline{P_i} = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall_i \tag{1}$$

In this equation, P_i is the value of *i*th parameter. P^*_i and P_{*i} are the best and standard value of the *i*th sustainable parameter. The best value of a parameter represents the best practice available and the worst value represents the standard practice or the minimum legal requirement.

Normalization in addition to turning dimensionless the value of the parameters considered in the assessment, converts the values into a scale bounded between 0 (worst value) and 1 (best value). This equation is valid for both situations: "higher is better" and "lower is better".

As stated before, building sustainability assessment across different fields and involves the use of numerous indicators and tens of parameters. A long list of parameters with its associated values won't be useful to assess a solution. The best way is to combine parameters with each other inside each dimension in order to obtain the performance of the solution in each indicator (Allard, 2004).

The methodology uses a complete aggregation method for each indicator, according to Equation 2.

$$I_j = \sum_{i=1}^{n} w_i \,.\overline{P_i} \tag{2}$$

The indicator I_j is the result of the weighting average of all the normalized parameters $\overline{P_i}$.

w_i is the weight of the *i*th parameter. The sum of all weights must be equal to 1.

Difficulties in this method lie in setting the weight of each parameter and in the possible compensation between parameters. Since weights are strongly linked to the objectives of the project and to the relative importance of each parameter in the assessment of each indicator, higher weights must be adopted for parameters of major importance in the project. The possible compensation between parameters is limited inside each indicator.

In what concerns to the weights of the environmental parameters, there aren't national impacts scores for each environmental parameter, according to its relative importance to overall performance. Although, there are some international accepted studies that allow an almost clear definition. Two of the most consensual lists of values are based on a US Environmental Protection Agency's Science Advisory Board study (EPA, 2000).and a Harvard University study (Norberg-Bohm, 1992). Whenever there isn't a local or regional available data, it is suggested to use SAB's weights in MARS-RE. Table 1 presents the relative importance of environmental parameters and indicators that is considered in the methodology. Values are adapted from the SAB's study.

Table 1. Relative importance weights for environmental parameters, adapted from the Science Advisory Board study.

Indicator	Impact parameter	Parameter's Weight (%)	Indicator's Weight (%)
Climate change	Global warming potential	22	22
Emissions	Destruction of the stratospheric ozone layer	15	47
	Acidification potential	15	
	Eutrophication potential	15	
	Formation of ground-level ozone (smog)	17	
	Inert waste to disposal[1]	6	
	Hazardous waste to disposal[2]	32	
Water efficiency	Potable water use[3]	75	4
	Rain water use[3]	25	
Resources depletion	Land use[1]	37	27
	Materials resource depletion[1]	37	
	Fossil fuel depletion potential	26	

[1] This parameter was connected with the habitat alteration impact category of the SAB study.
[2] This parameter was connected with the habitat alteration and ecological toxicity impact categories of the SAB study.
[3] This parameter was connected with the water intake impact category of the SAB study.

In spite of being easy to quantify the functional parameters, the way as each parameter influences the functional performance and therefore the sustainability isn't consensual. This assessment involves subjective rating and depends, above all, on the type of solution and on the valuator's social-cultural and economic status. This way in a first approach the methodology considers the same weight for all functional parameters. The MARS-RE is being developed in order to accommodate a more consensual distribution of weights.

3.6 *Representation and global assessment of a project*

One important feature of the methodology is the graphical representation for the monitoring of the different solutions that are analyzed. The representation is global, involving all the considered objectives (indicators).

The tool that is used to graphically integrate and monitor the different parameters is the "radar" or Amoeba diagram. This diagram has the same number of rays as the number of parameters under analysis and is called the sustainable profile. In each sustainable profile the global performance of a solution is monitored and compared with the performance of the reference solution. Furthest to the center is the solution, better it is. It is also possible to verify the solution that best compromises the different parameters used in the assessment. Figure 4 represents two sustainable profiles that result from the application of the MARS-RE to two hypothetical solutions.

The assessment of a project will come from the visualization of all indicators. Analysing figure 4 it is possible to verify that the solution that best compromises the objectives of the project is the most circular one. MARS-RE is an iterative design method, which is used to identify and to overcome the weaknesses of a project but it could not be used to assess the sustainability of a solution in an absolute way. It is used to compare different solutions in order to recognize the one that best suits the objectives of the project. After assessing the performance of a solution within all indicators as presented in Figure 2 the next step is to combine the indicators with each other inside each dimension in order to obtain the environmental, societal and economic performance of each solution, as presented in Equation 3 for the environmental dimension.

$$P_{Env} = \sum_{i=1}^{n} I_{Env_i} . w_{Env\,i} \qquad (3)$$

P_{Env} represents the environmental performance of the solution, I_{Envi} the *i*th environmental indicator and w_{Envi} is the weight of the *i*th indicator.

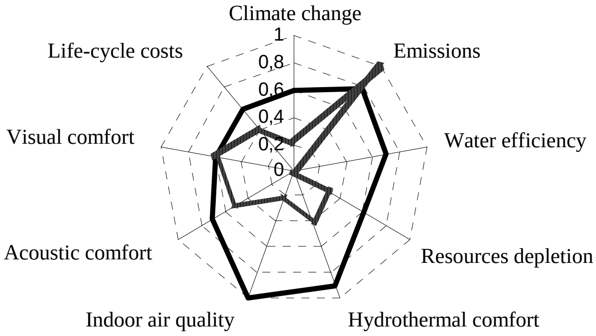

Figure 4. Sustainable profile.

The last step is the quantification of the Sustainable score (SS). SS is a single index that resumes the global performance of a solution. As nearest to 1 is the sustainable score, more sustainable is the solution. The aggregation method used to calculate the sustainable score is presented in Equation 4.

$$SS = P_{Env}.w_{Env} + P_{Soc}.w_{Soc} + P_{Eco}.w_{Eco} \qquad (4)$$

Since that the main aim of the sustainable development is the balanced development within the three dimensions, MARS-RE considers as standard an equal weight for each dimension in the integrated assessment. Although, users can use another set of weights, according to specific local priorities. In order to prevent difficulties in sustainability assessment, this unique mark should not be used alone to classify the sustainability because there is the possible compensation between indicators and moreover the solution has to be the best compromise between all different indicator.

4 CONCLUSIONS

Sustainable design, construction and use of buildings are based on the evaluation of the environmental pressure (related to the environmental impacts), social aspects (related to the users comfort and other social benefits) and economic aspects (related to the life-cycle costs).

In this paper it was presented some approaches to the buildings sustainability assessment (BSA) and one tool that is being developed to assist the Portuguese design teams in the sustainable design. Despite the numerous studies about it there is a lack of a worldwide accepted method to assist the architects and engineers in the design, production and refurbishing stages of a building. The actual LCA methods and building rating tools have a positive contribution in the fulfilment of sustainable developing aims, but they have their subjective aspects, for example, the weight of each parameter and indicator in the evaluation. For this reason, nowadays, the use of Performance Based Buildings methods, supported in the best construction codes and practices, to guide the design teams in order to archive the performance objectives, continues to be more objective than the use of rating tools.

The sustainable building rating tool that is being developed intends to contribute positively to the sustainable construction in Portugal through the definition of a list of goals and aims, easily understandable by all intervenient in construction market, compatible with the Portuguese construction technology background. Although, there are still two important steps to fulfil before applying the methodology: validation of the list of indicators and parameters and assessment of the societal weights. Although the list of indicators and parameters is partially based in the framework for assessment of integrated building performance (CEN/TC 350), further work includes its validation in Portugal through thematic interviews and surveys to experts in each dimension of the sustainable development. The weight of each health and comfort related parameter is now being assessed through experimental works and subjective evaluations.

The uptake of sustainable building design is in its infancy. Even with the actual limitations linked to the different methods available, the widespread of assessment methods is gradually gaining more market in the construction sector. Globally, the urgency to turn the economic growth toward sustainable development will require more efforts in the construction sector, too.

5 REFERENCES

Allard, F., Chéqui, F., Wurtz, E. and Mora, L. 2004. A methodology to assess the sustainability of rehabilitations projects in urban buildings. LEPTAB, University of La Rochelle, France.

Agenda 21 on sustainable construction. 1999. CIB Report Publication 237. Rotterdam, the Netherlands.

Berge, B. 2000. Ecology of building materials. Traduction from the original Norwegian title “Bygnings materialenes okologi”. 1ª Ed. Oxford: Architectural Press.

Bussemey-Buhe C. 1997. Dévelopment d’une méthode de conception environmental des bâtiments prenant en compte l’environnement de proximité. Ph. D. Thesis, Université de Savoie, Savoie, France.

CEN/TC 350 WG1. Sustainability of construction works – Assessment of environmental performance of buildings – Calaculation methods. Working Draft N024. January, 2007.

Cherqui, F. & Wurtz, E & Allard, F. 2004. Elaboration d’une méthodologie d’aménagement durable d’un quartier. Annales du bâtiment et des travaux publics. 1ª Ed. Pág. 38-34.

Diaz-Balteiro L.& Romero C. 2004. In search of a natural systems sustainability index. Ecological Economics; 49, pp 401-405.

Edwards, S. & Bennett, P. 2003. Construction products and life-cycle thinking. UNEP Industry and Environment, Apr.-Sep., p. 57-61.

Environmentally Sound Technologies for Sustainable Development, Rev. Draft 21/09/03. 2003. United Nations Environment Programme. International Environmental Technology Center, Div. of Technology, Industry and Economics.

EPA. 2000. Toward Integrated Environmental Decision-Making. United States Environmental Protection Agency, Science Advisory Board, EPA-SAB-EC-00-011, Washington, D.C., August and United States Environmental Protection Agency & Science Advisory Board. Reducing Risk: Setting Priorities and Strategies for Environmental Protection, SAB-EC-90-021, Washington, D.C., September, pp 13-14.

Erlandsson M. & Borg M. 2003. Generic LCA-methodology for buildings, constructions and operation services – today practice and development needs. Building and Environment 38(2003)p. 919-938.

Forsberg A. & Malmborg von F. 2004. Tools for environmental assessment of the built environment. Building and Environment 39. 2004. Issue 2, pages 223-228.

Geissler S. & Macoun T. Austrian state-of-the-art report, CRISP project.

Kibert, Charles J. 2003. Forward: Sustainable Construction at the Start of the 21st Century. International Electronic Journal of Construction (IeJC).

Koukkari, H. & Huovila, P. 2005. "Improving the performance of buildings". in Schaur C., Mazzolani F., Huber G., De Matteis G. Trumpf H., Koukkari H. Jaspart J-P. & Braganca L. (edts). Proceedings of the Final Conference of COST Action C12 - Improvement of Building's Structural Quality by new Technologies, pp 425-430. Innsbruck, Austria, 20-22, January. Balkema Publishers, ISBN: 04-1536-609-7.

Kurtz J.C. & Jackson L.E. & Fisher W.S. 2001. Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency’s Office of Research and Development. Ecological Indicators; 1 pp 49-60.

Norberg-Bohm, V. 1992. International Comparisons of Environmental Hazards: Development and Evaluation of a Method for Linking Environmental Data With Strategic Debate Management Priorities for Risk Management, Center for Science & International Affairs, John F. Kennedy School of Government, Harvard University, October.

Pushkar S., Becker, R. & Katz, A (2005). A methodology for design of environmentally optimal buildings by variable grouping. Building and Environment 40pp. 1126-1139.

Roodman, D.M.& Lenssen, N.1995. A Building Revolution: How Ecology and Health Concerns are Transforming Construction. Worldwatch Paper 124, Worldwatch Institute, Washington DC, March, 1995.

Life cycle assessment of construction processes

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ABSTRACT: Life cycle assessment (LCA) is a methodology by which the environmental impacts of a product or a process can be evaluated throughout its life cycle. The methodology can serve as a decision tool in the selection of construction materials and optimization of construction processes. The paper presents the theoretical background of a particular method, and to demonstrate its flexibility and capabilities, a case study of a reinforced concrete wall cast in situ is analysed. Based on the inventory of all materials and processes required for this wall, the LCA analysis is carried out. Various scenarios for the selection of the different constituent materials of the were considered, and the results show that the selection of different concrete constituent materials has a major influence upon the environmental parameters, in particular, energy use and global warming. The analysis clearly shows the selection of the cement type (in terms of supplementary cementing materials content) is the single most important component of a reinforced concrete structure in terms of its environmental impact.

1 INTRODUCTION

Today's imperative of sustainable development (World Commission on Environment and Development 1987) manifests itself in various actions in many areas. One of the most important areas is assessment of environmental impacts caused by production, use and disposal of various products, Life Cycle Assessment (LCA). LCA is an objective procedure to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impact of those energy and material uses and releases on the environment, and to identify and implement opportunities yielding environmental improvements. The environmental impacts considered can be global such as greenhouse gases, regional, such as acid rain, or local, such as smog formation (Osman and Ries 2006). The method evaluates all stages of a product life, including raw materials extraction, production, use and disposal.

The method has been increasingly used in the production of consumer goods and as a tool to assess and decide among alternative technologies or products; however, it has not been widely used to analyse construction products and building production and use; only in recent times, an increasing body of literature has dealt with this area (e.g. Asif *et al* 2007; Koroneos and Dompros 2007; Schuurmans *et al* 2002; Josa *et al* 2004; Schmidt *et al*, 2004; Nixon *et al* 2004; Treloar *et al* 2004; Jonsson 1998), as revealed by an extensive literature search.

Worldwide, it is estimated that approximately 40% of the total energy consumed, 40% of all the waste produced, and 40% of all virgin raw materials consumed are associated with the building/construction sector. In today's world, only consumption of water is larger than the total production of petrous materials to be further used in construction. The LCA end-results will lead to the minimization of the use of the above mentioned raw material resources and the inherent environmental impacts, while being extremely beneficial toward the rationalization of the final product of the construction industry, while ensuring the sustainable development of the sector.

In contrast with the products for wide consumption, buildings are designed and constructed for a long service life. The specified service life depends very much on the importance of the building. A building is a complex product that consists of many building products, which are permanently built in (Construction Products Directive 1988) with a relatively long production period. Therefore, a life cycle assessment can be applied either to a whole building, taking it as a product (e.g. Asif et al 2007), or to an individual construction product (e.g. Koroneos and Dompros 2007).

2 METHODOLOGY

Life cycle assessment methodology became standardized with the introduction of the international standards ISO 14040 (1997), ISO 14041 (1998), ISO 14042 (2000) and ISO 14043 (2000). The standard analysis contains the following steps:

- Goal and scope definition
- Inventory analysis
- Impact assessment and
- Interpretation

Life Cycle Inventory (LCI) involves tracking of all flows in and out of the system of interest – raw resources or materials, energy by type, water, emissions to air, water and land by specific substance.

The results presented in this study were obtained by using an LCA tool developed by the European Ready-Mix Concrete Association (ERMCO) particularly to assess the applicability of the LCA for production of reinforced concrete structures. Several LCA methodologies are embedded in the program: CML2001 (Guinée 2001), EDIP (Wenzel et al 1997) and Eco-Indicator (Goedkoop et al 2001). All these methodologies meet the ISO 14042 requirements and are being recognized throughout Europe.

The tool was developed specifically for analysis of concrete and reinforced concrete elements. It is not intended for the analysis of the building and its performance during its use. Even so, different end-of-life scenarios and levels of recycling can be projected in the analysis.

2.1 *Selection of functional unit*

Understanding the concept of functional unit is essential for proper execution of Life Cycle Assessment Analysis. The assessment is carried out on a functional unit, therefore, it should describe the function of the product or process being studied. Its careful selection will improve the accuracy of the comparative study and usefulness of the results. A simple example of a well chosen functional unit would be the selection of a m^2 of insulating material with a defined thermal insulation capacity. If two insulation materials were compared in terms of their environmental impact, and material A would have larger insulation capacity compared to material B, then the functional units for these two materials would have to have different thicknesses.

3 CASE STUDY

One of the most commonly encountered types of a building's structural element, a cast in situ reinforced concrete wall, was selected as a case study. The production of the wall is schematically presented in Figure 1, in which the raw materials, by-products and energy flows, including suppliers, customers and waste treatment transport, are represented.

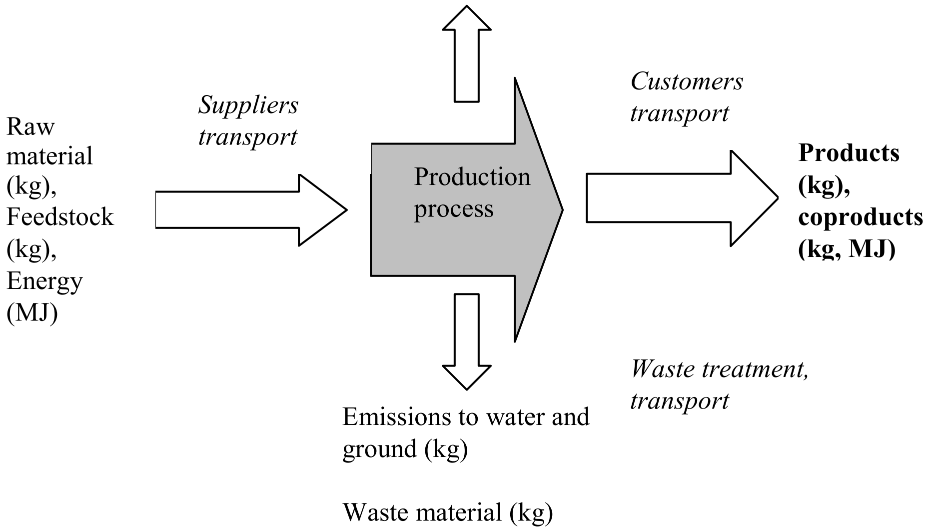

Figure 1. Materials and energy flows according to the CML2001 methodology (Meijer, 2003)

3.1 *Production process description*

The concrete plant supplying concrete to the construction site, where the wall is being constructed, is 100 km away from the site and reinforcement is supplied from a plant 80 km away from the site as depicted in Fig. 2. Trucks with varying capacities are employed to transport the constituent materials to the concrete plant, and reinforcement and fresh concrete to the construction site. The distances from the concrete plant to aggregate producer (quarry), production of cement and additives (plasticizers) and other data defining the reference case, such as concrete mix design, end-of-life scenario and final waste treatment are collected in Table 1. It is assumed that at the end of life, 95% of both concrete and reinforcement are recyclable.

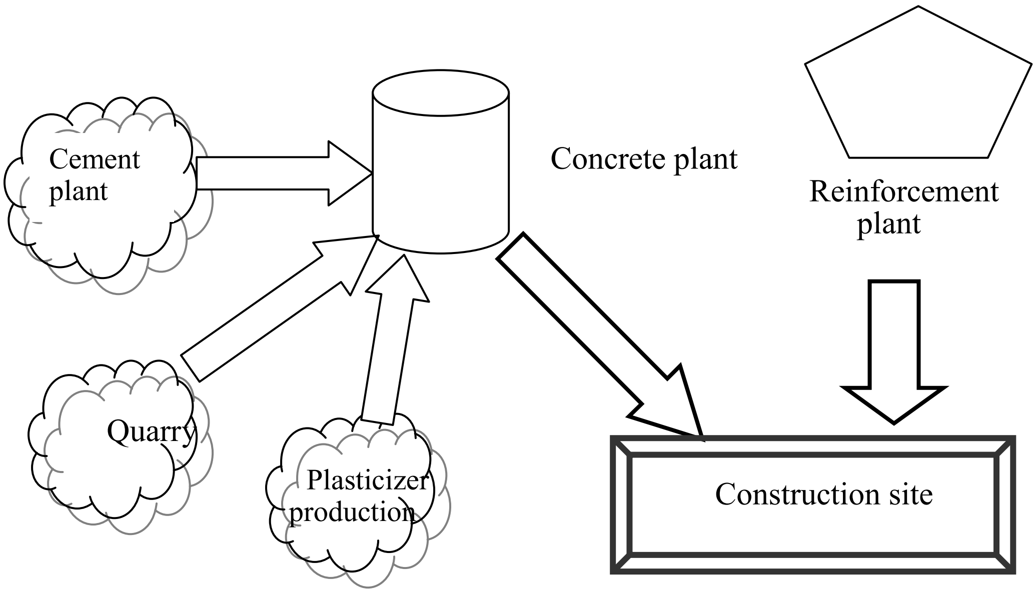

Figure 2. Schematic presentation of cast in suit reinforced concrete wall production

Table 1. Input data for the life cycle assessment analysis of reinforced concrete wall cast-in-situ.

Functional unit	Quantity	Quant. / m2
Area	1 m2	
Corresponding mass of concrete	0.508 t	
Concrete mix composition		
CEM I 52.5	365 kg/m^3	73 kg
Cement transport (truck cap. 28 t)	100 km	
Coarse aggregate	800 kg/m3	160 kg
Fine aggregate	1200 kg/m3	240 kg
Aggregate transport (truck cap. 28 t)	80 km	
Plasticizers	3.3 kg/m3	1 kg
Transport of plasticizers (truck cap. 28 t)	250 km	
Reinforcement	45 kg/m3	9 kg
Reinforcement transport (truck cap. 28 t)	100 km	
Water	125 l/m3	25 kg
Truck 28 t (transport)	202 t km/m3	40 t km
Life cycle - construction		
Reinforced concrete wall	1	508 kg
Transport to site		
Truck 40 t	100 km	
Truck 40 t	50.8 t km	50.8 t km
Demolition		
Demolition		508 kg
Final waste treatment		
Waste concrete	5 %	0.025 t
Recyclable concrete	95 %	0.474 t
Waste steel	5 %	0 t
Recyclable steel	95 %	0.009 t
Truck 28 t (transport to landfill)	25 km	12 t km

3.2 *Analysis and results*

Casting of the reinforced concrete wall was analyzed by using the CML2001 methodology (Guinée 2001).

The complete results obtained by using LCA are presented in Table 2. The largest environmental impact emerges from the cement, and the results also indicate the second largest environmental impact is generated by the transportation by truck, when taken as a single group.

The indicator results presented in Table 2 are expressed in conformance to the methodology of CML2001 (Guinée, 2001). The units employed are therefore kg of the reference resource antimony (Pb) for abiotic depletion potential, kg 1.4 DB (dichlorobenzene) equivalent for toxicity, kg SO_2 equivalent for acidification, and kg CO_2 equivalent for global warming potential.

Table 2 clearly shows the dominant influence of cement on the overall environmental impact of the cast-in-situ reinforced concrete wall; 48% of all energy, and 68% of all produced CO_2 required to produce a m^2 of concrete wall is used for the cement production. Despite large quantites, the contribution of aggregate to the overall environmental impact of the wall is almost negligible and it represents less than 1% of the total value of all environmental indicators considered.

Table 2. Contributions of individual processes and materials upon environmental impacts during the life cycle of a reinforced concrete wall.

	Energy (MJ)	Human toxicity (kg 1.4 DB)	Abiotic source depletion (kg Sb)	Acidification (kg SO_2)	Climate change (kg CO_2)
Cement	456.250	2.365	0.424	0.134	65,554
Aggregate	12.200	0.074	0.054	0.004	0.596
Plasticizers	4.244	0.055	0.026	0.006	0.256
Reinforcement	83.430	5.922	0.338	0.028	4.266
Water	0.000	0.000	0.000	0.000	0.000
Transport – const. materials	83.959	1.025	0.848	0.054	6.337
Production	65.996	0.376	0.640	0.017	3.807
Transport to site	64.473	0.782	0.650	0.042	4.858
Construction	12.336	0.151	0.125	0.008	0.934
Maintenance	0.000	0.000	0.000	0.000	0.000
Demolition	104.070	1.005	0.985	0.047	6.701
End-of-life scenario	58.379	0.566	0.515	0.022	3.512
Total	945.337	12.321	4.605	0.361	96.822

The sensitivity study was therefore conducted for two different concrete mixes containing different cement types in different quantities. Concrete mix design employed in the analysis is presented in Table 3. Cement Type I (CEM I) used in the reference mix is replaced by Type II (CEM II), which contains up to 20% of supplementary cementing materials. The two mixtures have approximately equivalent compressive strength of concrete; therefore, the bearing capacity of the wall that defines the functional unit does not change due to the concrete mixture design change.

The LCA results for the two concrete mix designs, CEM I and CEM II, respectively, is presented in Table 4 for energy usage, CO_2 and toxic substance emissions. The results of the simulation reveal a significant reduction of energy consumption in the production and disposal of the concrete wall, when built with CEM II cement type; this is due to the increased content of mineral additives in this cement that do not require high temperature kiln-burning. In what concerns climate change impact, i.e. CO_2 production, CEM I and CEM II yield practically identical results; however, CEM II has lower terrestrial eco-toxicity and slightly higher acidification than those of CEM I.

Table 3. Concrete mix design used in sensitivity analysis to assess the influence of cement type and influence of concrete mix design upon used energy and CO_2 production, and toxic substance emission upon ground, water and air.

	Reference case (CEM I 52.5 Europe)	**Changed mix design** (CEM II/A-L 32.5R Europe)
Cement	365 kg/m^3	410 kg/m^3
Coarse aggregate	800 kg/m^3	960 kg/m^3
Fine aggregate	1200 kg/m^3	790 kg/m^3
Plasticizers	3.3 kg/m^3	6.1 kg/m^3
Water	125 l	175 l

Table 4. Sensitivity analysis: LCA results for the reference and changed case of concrete mix design.

	Reference case (CEM I 52.5 Europe)	**Changed mix design** (CEM II/A-L 32.5R Europe)
Energy	945.2 MJ	812.4 MJ
Climate change	96.8 kg CO_2	102.4 CO_2
Terrestrial ecotoxicity	0.128 kg 1.4 DB	0.087 kg 1.4 DB
Acidification	0.361 kg SO_2	0.411 kg SO_2
Eutriphication	0.074 kg PO_4^-	0.082 PO_4^-

The results presented in Table 2 show that during the disposal stage, the level of recycling has a major effect upon environmental profile of the reinforced concrete wall. The second sensitivity study was therefore carried out for different levels of concrete and reinforcement recycling, that is carried out after the demolition. Results for major environmental indicators presented in Table 5 for 5, 50 and 95% recycling rate show that total energy used in the life cycle of the wall is affected for less than 5% when the level of recycling increases from 5 to 95%. The largest influence is observed for inert waste, which is significantly reduced when recycling level is increased.

Table 5. Influence of recycling rate upon selected environmental indicators.

	recycling level		
	5%	50%	95%
Energy (MJ)	990,866	968,102	945,337
Non-chemical waste (kg)	475,226	255,676	36,126
Chem.waste (kg)	0,019	0,014	0,008
Human toxicity (kg 1,4 DB)	12,589	12,455	12,321
Abiotic source depletion (kg Sb)	4,826	4,716	4,605
Eco-toxicity fresh water aquatic (kg 1,4 DB)	1,514	1,468	1,422
Eco-toxicity fresh water sediment (kg 1,4 DB)	2,504	2,426	2,349
Eco-toxicity terrestrial (kg 1,4 DB)	0,134	0,131	0,128
Climate change (kg CO_2)	100,665	98,744	96,822
Photo oxydant formation kg C_2H_4	0,021	0,020	0,019

4 DISCUSSION AND CONCLUDING REMARKS

The analysis for the base case of a cast in situ reinforced concrete wall using the CMLCA methodology reveals that cement is the leading single component in what concerns environmental impact in all categories considered, namely: energy usage, human toxicity, abiotic resources, acidification, and climate change. It is interesting to note that in terms of energy usage demolition is second only to cement (104.1 vs. 456.2 MJ). The combined transport component is, when all the categories are considered and after the cement, the one with the largest environmental impact. This result is not unexpected taking into account the relatively large distances (100 km) to be travelled by the concrete, which are considered in the case study. It is surprising, however, to note that reduced distances do not lead to significant reductions of toxic substance emissions. The sensitivity analysis also serves to demonstrate the ability of selecting the construction material, in this particular case cement composition, based on the LCA methodology. The two mixes with different cement types, CEM I and CEM II, although with different compositions, yield similar results with an advantage of 14% in terms of energy usage for CEM II, but yielding a 13.8% increase in acidification. Obviously, with the guidance of the LCA methodology, different mixes with similar strength can be designed to yield reduced environmental impact.

The proposed procedure and the case study used for its illustration clearly indicate the potential of LCA as a decision tool in what concerns buildings, and, in particular, building components. The designer can make an educated choice when selecting the best-suited construction material, while the construction planner can use as a component of the decision process the environmental impact due to the relative distances of the suppliers.

REFERENCES

Asif, M., Muneer, T., Kelley, R. 2007. Life cycle assessment : A case study of a dwelling home in Scotland. *Building and Environment*, 42(3): 1391-1394.

Construction Products Directive, Council Directive 89/106/EEC of 21 December 1988, European Commission, Bruxelles.

EPA 2006.: U.S. Environmental Protection Agency and Science Applications International Corporation. LCAccess – LCA 101 (available at http://www.epa.gov/nrmrl/lcaccess/)

Goedkoop, M., Spriensma, R. 2001. *A damage oriented method for Life Cycle Assessment – Methodology Report*, 3rd Ed., Amersford, The Netherlands, 144 pp. (available at www.pre.nl)
Graedel, T.E., and Allenby, B.R. 2003. *Industrial Ecology*, 2nd Edition, Prentice Hall, Englewood Cliffs, NJ, 363 pp.
Guinée, J. (editor) 2001. *Life cycle assessment: An operational guide to the ISO standards*, Leiden University, centre for Environmental Sciences, 601 pp. (available at http://www.leidenuniv.nl/cml/ssp/index.html)
ISO 14040 1997. Environmental management – Life cycle assessment – Principles and framework. International Standards Organization, 11 pp.
ISO 14041 1998. Environmental management – Life cycle assessment – Goal and scope definition and inventory analysis. 21 pp.
ISO 14042 2000. Environmental management – Life cycle assessment – Life cycle impact assessment. 15 pp.
ISO 14043 2000. Environmental management – Life cycle assessment – Life cycle interpretation. 18 pp.
Jönsson, T. Björklund and A-M. Tillman, A.M. 1998. LCA of concrete and steel building frames. *International Journal of Life Cycle Assessment,* **3**(4): 2116–2224.
Josa, A., Aguado, A., Heino, A., Byars, E., Cardim, A. 2004. Comparative analysis of available life cycle inventories of cement in the EU. *Cement and .Concrete Research*, 34: 1313-1320.
Koroneos, C., and Dompros, A. 2007. Environmental assessment of brick production in Greece. *Building and Environment*, 42(5): 2114-2123.
Meijer, J.P.R. 2003. *Learning about and work with EcoConcrete*. EcoConcrete course book 1.1, 32 pp
Nixon, P., Quillin, K., Somerville, G. L. 2004. Life-cycle assessment/analysis of concrete. *Concrete,* 38: 31-33.
Osman, A.E., and Ries, R. 2006. Optimization for cogeneration systems in buildings based on life cycle assessment. *ITcon*, 11:269-284.
Schmidt, A.C., Jensen, A.A., Clausen, A.U., Kamstrump, O., Postlethwaite, D.L. 2004. A comparative life cycle assessment of building insulation products made of stone wool, paper wool and flax. *Int. J. of life cycle assessment*. 9(2): 122-129.
Schuurmans, A., Tukker, A., Mulder, E., L. 2002. LCA for the »Closed Building Cycle« system. An indicative LCA of the autonomous development and the closed building cycle, *10th SETAC LCA Case Studies Symposium.*
Treloar, G.J., Love, P.E.D., Crawford, R.H. 2004. Hybrid life-cycle inventory for road construction and use. *ASCE Journal of construction engineering and management*, 130(1): 43-49.
Trusty, W.B., and Horst, S., L. 2002. Integrating LCA Tools in Green Building Rating Systems, (available at http://www.athenasmi.ca/)
Wenzel, H., Hauschild M., Alting L. 1997. *Environmental Assessment of Products,* Chapman & Hall, UK.
World Commission on Environment and Development, *Our common future,* 1987,. Oxford Press, UK.

Optimization of variable selection for sustainable construction

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ABSTRACT:

According to a life cycle analysis (LCA), proper selection of all building variables and components requires the calculation of their environmental impact throughout their entire life cycle, which leads to numerous calculations. The objective of this study was to establish a methodology for the identification of design variables with minimum environmental impact, yet using relatively simple calculation procedures. The methodology comprises three steps: (1) Grouping the variables into distinct, stand-alone groups that enable to break down the entire life cycle calculation into several independent optimization procedures; (2) Optimization of the variables within each group; (3) Integration of all the solutions.

The methodology was applied to a typical office building. It was shown that the life cycle approach, combined with optimization tools, can successfully ascribe most of the design variables into three independent groups. Sensitivity analysis showed that variables allocation depends on regional characteristics (climate, energy production etc.).

1 INTRODUCTION

A building, including all of its components, is a complex product that affects the environment during all stages of its life cycle, from construction through service life until complete demolition. The building sector is a major consumer of natural resources. It consumes some 25% of the forest wood, 16% of the fresh water, and 40% of the raw stone, gravel and sand used throughout the world each year (Dimson, 1996). In addition to the consumption of raw materials, the building sector is a significant consumer of energy, thus accounting for a significant amount of carbon dioxide emission throughout the operation time of a structure, which may last one hundred years and more.

Reducing the environmental impact of buildings and building-related activities is thus an important task that should be considered early during the design stage of a building. A wealth of literature is available on the optimization design related to energy (Shariah et al., 1998; Kalogirou et al, 2002; Becker and Paciuk, 2003). However, energy consumption during the operational stage of building life is only one aspect of the entire life, and a comprehensive approach that takes into account the entire building life "from cradle to grave" must be considered. A life cycle analysis (LCA) method, as outlined in the ISO 14040 series, can constitute a framework for such a comprehensive approach. This method has already been applied in the evaluation of some industrial products and processes (Dobson, 1996; De Langhe et al., 1998; Dones and Frischknecht, 1998; Alexander et al., 2000).

According to the LCA method, proper selection of all building variables and components requires the calculation of their environmental impact throughout their entire life cycle, i.e. from the quarrying of the raw materials, throughout the building's entire service life, until final demolition. The number of variables to be considered is extremely large, leading to an even greater number of calculations. In order to facilitate these calculations, some simple methods were developed that evaluate the environmental impact of a building. The most easy-to-use ones are based on a prescriptive approach that lists a series of simple guiding rules, which, when fulfilled, will make the building more environmental friendly. These tools, such as LEED in the US and BREEAM in the UK, are gaining in popularity due to their simplicity, but lack a scientific basis that will enable to compare solutions to optimize their selection. Other tools, such as BEES (Lippiatt, 1999), provide a more comprehensive calculation of several building materials and components, as well as a calculation of their economic performances based on their use in North America. Optimization of an entire building over its entire life cycle is still limited.

The objective of this study was to establish a methodology for optimizing the selection of design variables, with minimum environmental impact of the entire building, yet using relatively simple calculation procedures.

2 METHODOLOGY

2.1 Grouping

The methodology is based on the assumption that the multitude of building variables can each be ascribed to a small number of groups and that optimization can be performed individually within each group without losing the scientific basis of the calculation. It is assumed that variables can be aggregated into such groups based on the greatest environmental impact related to the group, provided there is a significant difference between these impacts. Consequently, each variable would be optimized with respect to the group in which it has the greatest impact. The resulting combination will yield the overall optimal solution that would have been obtained by optimizing the entire population over the entire life cycle, but with less calculation power.

The methodology comprises three steps (Fig. 1): (1) Grouping the variables into distinct stand-alone groups that enable to break down the entire life cycle calculation into several independent optimization procedures; (2) Optimization of the variables within each group; (3) Integration of solutions. In order to facilitate the calculation, the building is scanned first to identify basic repetitive modules, such as identical floors or sections. In such a case, the calculation can be performed on this particular module only.

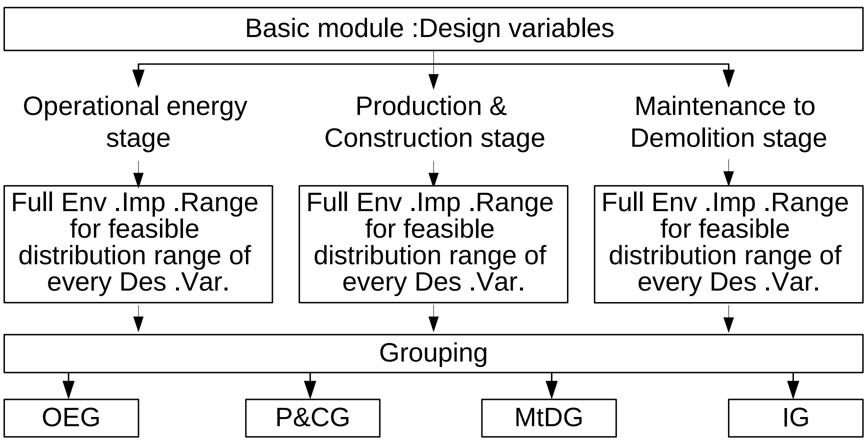

Figure 1: Scheme of grouping procedure.

Two main phases were identified in view of their environmental impacts: pre-occupancy, and post-occupancy. The former is affected directly by quantities of materials, their availability and construction methods whereas the latter is affected by routine use and maintenance practices. The first group therefore includes activities related to production and construction (P&CG). The second and third groups include activities related to the post-occupancy phase. Energy for the routine operation of the building was found to be a stand-alone category. Its environmental impact is significant and it is affected by the selection of materials, acclimatization methods, glazing dimensions, ventilation rates and other parameters that lead to a non-linear accumulation of the environmental impacts. Other maintenance activities, such as renovation and rehabilitation, are, in fact, repeated activities involved in the construction and demolition of particular elements or components. The second and third groups were, therefore, defined as the operational energy group (OEG) and the maintenance to demolition group (MtDG), respectively. A fourth group, the integrated group (IG), that contains variables relevant to several life cycle stages, was also identified.

Grouping is based on scanning the environmental impacts associated with each life cycle stage of the range of solutions for a particular variable, thus establishing the full environmental impact range (FEIR) for this variable. Variables that clearly exhibit the greatest environmental impact in a single stage are assigned to this stage.

Thus, for example, the environmental impact of each of the possible solutions for partition walls are analyzed within each of the above groups to determine the full environmental impact range of all the solutions. If all of the solutions exhibit a significantly large environmental impact in one of the three individual groups, then this design variable (partition wall, in this example) is assigned to this particular group, otherwise, it is assigned to the fourth group, the integrated group.

Since the environmental impact of materials and elements in the P&CG and MtDG groups is almost a linear function of their quantities, calculating their impacts is relatively simple. Parameters that refer to operational energy are non-linear and another method of calculating their impact was developed as follows:

First, the optimal combination of variables for minimum environmental impact is determined as the base point for the rest of the calculations. Optimization, at this stage, requires use of a reliable but fast algorithm, such as the Genetic Algorithm [Holland 1975], in order to cope with the complexity of this calculation. It should be noted that the objective of this calculation is not to achieve minimum energy consumption, but rather minimum fuel consumption that depends on energy production processes and acclimatization equipment. The range of solutions for each of the building variables is then compared with the optimum obtained previously, to determine the FEIR for this group.

2.2 Optimization

Optimization is done to achieve two objectives: minimization of both the environmental impact and of the cost of the solution.

In order to achieve these two objectives, optimization is done using the indifference curve technique, which is known for its solution of multi-objective problems (Hwang and Masud, 1979). According to this method, the various solutions are plotted on an X-Y plot, using a relative scale. The best solution for each objective is assigned the zero value, whereas the worst solution is assigned the 100% value. The distance of each solution from the origin, on the X-Y plane, determines its ranking relative to the other solutions. The best solutions are obviously found closest to the origin. Figure 2 demonstrates this approach. Solutions 2 and 3 have the same ranking, thus it is impossible to determine which one of them is better .It is, however, clear that Solution 1 is better than the others in terms of both environmental performance and cost performance.

3 EXAMPLE OF APPLICATION - OFFICE BUILDING

An example of an office building was chosen to demonstrate the methodology. An office building can be represented by a single repeating unit located in the main body of the building (intermediate floor, not in a corner). Similarly, a single apartment or a single floor can be taken as the repeating unit in a residential building or multi-floor building, respectively. For our example, we selectd a unit 3 m wide by 4 m long and 3 m high, with three partition walls and one external wall. Table 1 lists the decision variables for this unit i.e. all variables that might be selected during the design of the building. For example, five solutions are commonly-used in Israel for partition walls. Each solution has a certain impact on the environment during the construction stage and during its service life (renovation and rehabilitation) and it may have an impact on the consumption of energy for heating and cooling.

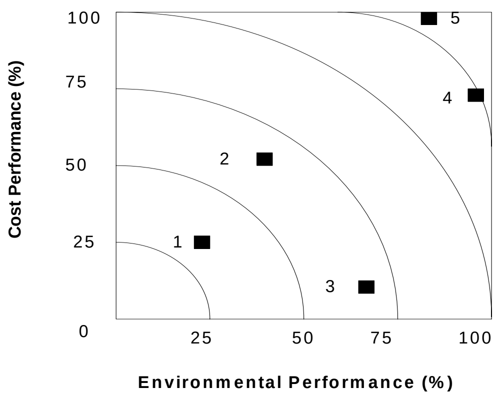

Figure 2: The indifference curve technique used to optimize both environmental and cost performances.

For the purpose of operational energy calculation, the service conditions must be defined first. For this example, it was assumed that the office is occupied by one person, eleven hours a day (7am to 6pm), 5 days a week. Room temperature is set to 20°C for heating regime and 24°C for cooling regime and heating and cooling is done by a heat-pump (Coefficient of Performance, COP, of 2.75 and 3.0, respectively). Air exchange rate is $1h^{-1}$. Weather conditions were calculated according to meterology data for a typical year in Jerusalem, i.e. mild summer and cool winter. The required illuminance was set to 500 lx and additional source of power such as electric equipment was assumed to be 610W. Calculations were performed for a service life of 50 years.

Table 1: Decision variables

Variable	Alternatives
Partitions	Gypsum wallboard, concrete block, cellular block, gypsum block, or silicate block
Floor/ceiling	Flat reinforced concrete slab, ribbed slab with concrete blocks, ribbed slab with cellular blocks, or hollow-core pre-stressed concrete plate
Floor covering	Ceramic tile, terrazzo, marble, PVC, or carpet
External wall type	Wall types I, II, or III
External wall covering	Stone, ceramic tile, or plaster
Glazing	54 types
Window Size	Width and height from 0.3m to 2.7m at discrete steps of 0.3m
Insulation thickness	External and internal (0.0m to 0.2m at 0.01m intervals)
Concrete mass thickness	Internal and external (0.1m to 0.2m at 0.01m intervals)
Block thickness	0.2m to 0.3m at 0.01m intervals

Calculations were performed using the following tools:

- Thermal analysis - EnergyPlus (Crawley et al., 2001)
- Optimization of the thermal analysis using the genetic algorithm - GAOT (Houck et al. 1995).
- Environmental data processing and database - SimaPro 5.0 (Goedkoop and Oele, 2001), and additional database - BEET (Petersen, 1999).
- Life cycle assessment, LCA, - Eco-indicator 99

The environmental databases listed above contain a large number of alternatives for material, elements and processes. In addition, the data-processing tool enables to create new processes, provided that sufficient knowledge exists with respect to all of its details. When knowledge on the environmental impacts of all the construction processes was insufficient, data for construction activities was calculated based on environmental impacts resulting from the consumption of raw materials, their transportation to the construction site and the energy required for the on-site use of equipment during construction.

Eco-indicator 99 is a damage-oriented method that divides the damage into three groups: damage to human health, damage to ecosystems, and resources depletion. The data are processed into a single score (eco-points) using the concept of cultural theory (Thompson et al., 1990) and includes three methodological options that use different assumptions for damage time-frame (E- very long and not absolutely proven, I- very short and already proven, H- balanced) and for the required level of damage certainty (E, I and H as above and A- evenly distributed). It should be noted that all options for time-frame and level of damage uncertainties must be considered unless otherwise predetermined for a particular reason.

4 RESULTS AND DISCUSSION

4.1 Production and Construction Stage

Table 2 presents an example of the calculation of the full environmental impact range (FEIR) for the partition wall variable. Each alternative was analyzed thoroughly for its environmental impact. This impact was processed into a single score, expressed in eco-points, using the various approaches to the damage time-frame, as described above. The range of possible solutions for each calculation method was determined. Thus, the range for the I/A option extends between 11.3 for cellular blocks and 146.0 for concrete blocks, i.e. 134.7 pt. The minimal and maximal range was found to be 80.6 and 185.8, respectively; a value that expresses the difference between the most conservative and most liberal possible solutions.

Table 2: Environmental scores stemming from the production and construction stage for the partition wall variable (pt), calculated for different assumptions of time-frame and level of damage certainty.

Alternatives	I/A	I/I	H/A	H/H	E/A	E/E
Gypsum board	23.7	27.8	51.8	61.2	53.2	49.3
Concrete block	146.0	199.0	124.0	101.0	123.0	95.9
Cellular block	11.3	14.6	17.4	17.5	17.7	15.3
Gypsum block	43.5	55.6	63.9	64.3	78.7	70.1
Silicate block	11.3	13.7	27.8	29.4	26.5	23.3
Range	134.7	*185.3*	106.6	83.5	105.3	*80.6*

4.2 Operational Energy Stage

In order to find the FEIR for the operational energy stage, optimization of the module's variables was performed first to obtain the minimum electricity consumption. Each variable was then investigated for changes in the environmental impact stemming from the choice of a different alternative. The minimum and maximum were determined, leading to the results presented in Table 3. It should be noted that the calculation was done assuming service life of 50 years. Defining this period (service life) is important since the electricity demand increases linearly with the service life. Once the full range of electricity consumption was determined for each variable, the environmental impacts were calculated as described above.

4.3 Maintenance to Demolition Stage

The FEIR for each variable was determined similarly to the calculations described in the Production and Construction stage above, together with the negative impact of demolition and the positive impact of possible recycling. The life cycle of each variable was determined individually.

4.4 Determination of Group Allocation

Table 4 presents a summary of the results. Each variable was allocated to a specific group provided that its FEIR for one of the stages was significantly larger than for any of the other stages. Partition wall, for example, was allocated to the Production and Construction Group. Its FEIR for this group ranged between 81 and 185 eco-points, whereas it ranged from 7 to 35 and from 12 to 22 for the other two groups .It is therefore clear that this variable belongs to this group and further optimization for any similar building can be done within this group only. Allocation of the other variables into the appropriate group is presented in Table 4.

Table 3: Deviations from optimum of electricity demands for design variables' feasible ranges, assuming 50-year service life

Variable	Electricity Demand Deviation (kWh*50yr/m^2)				Range per m^2 (kWh*50yr/m^2)	Range per 12m^2 module (kWh*50yr/module)
	North	South	West	East		
Partitions	26.9	*46.2*	21.4	*18.2*	18.2 – 46.2	218.4 – 554.4
Floor/ceiling	*59.4*	102.6	*121.4*	89.3	59.4 – 121.4	712.8 – 1456.8
Floor covering	*16.6*	22.8	*28.6*	22.9	16.6 – 28.6	199.2 – 343.2
External wall type	*5.4*	*29.7*	24.8	9.7	5.4 – 29.7	64.8 – 356.4
External wall covering	*2.2*	1.3	*2.2*	*0.9*	0.9 – 2.2	10.8 – 26.4
Glazing type	*4565.8*	4054.7	3754.0	*3181.5*	3181.5 – 4565.8	38178.0 – 54789.6
Window size	*2355.2*	1188.3	1337.6	*1101.2*	1101.2 – 2255.2	13214.4 – 27062.4
External insulation thickness	*378.8*	486.6	*628.4*	471.9	378.8 – 628.4	4545.6 – 7540.8
Internal insulation thickness	*344.8*	450.8	*587.5*	437.4	344.8 – 587.5	4137.6 – 7050.0
External concrete thickness	*10.4*	18.2	*20.1*	10.7	10.4 – 20.1	124.8 – 241.2
Internal concrete thickness	10.2	*17.6*	14.5	*7.9*	7.9 – 17.6	94.8 – 211.2
Block thickness	*34.6*	48.4	*62.0*	44.6	34.6 – 62.0	415.2 – 744.0

Table 4: Design Variable Grouping

Variable	Full Environmental Impact Ranges per life cycle stage (Pt)			Group Allocation
	Production & Construction	Operational Energy	Maintenance to Demolition	
Partitions	81 – 185	7 – 35	12 – 22	P&CG
Floor/ceiling	110 – 263	45 – 92	8 – 13	P&CG
Floor covering	48 – 93	6 – 22	244 – 467	MtoDG
External wall type	37 – 97	2 – 23	10 – 22	P&CG
External wall covering	18 – 52	0 – 2	16 – 48	IG
Glazing	0 – 2	1240 – 3460	1 – 5	OEG
Window size	1 – 5	429 – 1710	2 – 11	OEG
Ext. insulation thickness	2 – 11	148 – 476	<1	OEG
Int. insulation thickness	2 – 11	134 – 445	<1	OEG
Ext. concrete thickness	36 – 105	4 – 15	7 – 14	P&CG
Int. concrete thickness	36 – 105	3 – 13	7 – 14	P&CG
Block thickness	17 – 47	13 – 47	2 – 5	IG

In addition to the allocation of each variable into the appropriate group, it is evident that the FEIR of window size and glazing type is much larger than that of all other variables, indicating that proper selection of this variable is of special importance for proper environmental design.

Sensitivity analysis showed that production of electricity using renewable energy, such as hydro power plants, may change group allocation. When hydro power is used for electricity production instead of coal (produced using French technology), as assumed in the previous calculations (Tables 2 and 3), the following variables moved from one group to another: wall size and insulation thickness moved from the OEG to IG group, and floor/ceiling and block thickness moved from IG to P&CG. Some of these changes were expected due to the significant impact of these variables on the electricity consumption for heating and cooling. Other sensitivity analysis showed that changing the electricity production method, from one type of fossil fuel to another, may also affect group allocation. Improving the recycling options for the materials, however, showed no impact on the group allocation of the variables.

5 APPLICATION TO A PARTICULAR OFFICE BUILDING

Once group allocation is determined for all design variables in general, this approach can be applied to a particular office building. As an example, we selected a three-story office building: 20 m long and 17 m wide, with 15 rooms on each floor, facing the four cardinal directions (north, south, west and east). Occupancy conditions were similar to those stated before (i.e. one person per office, 7 am to 6 pm, 5 days a week).

The cost and environmental impact of each alternative were calculated. Again, the environmental impact of all of the alternatives was examined for damage time-frame due to the uncertainties involved with the assessment of the environmental impacts. Optimization of the solutions was analyzed using the indifference curve technique, as illustrated in Figure 3. According to these calculations, the selection of gypsum board for partition walls, for example, yields the best solution. It should be noted that in view of its cost, this is indeed the cheapest solution but not the one with the least environmental impact. However, simultaneous optimization of the two objectives reveals this alternative to be the best. It can also be seen that different environmental approachs, (H/H and E/E, very long time-scale consideration only or balanced long and short time-scale) may add another alternative (cellular block) to the selected solutions.

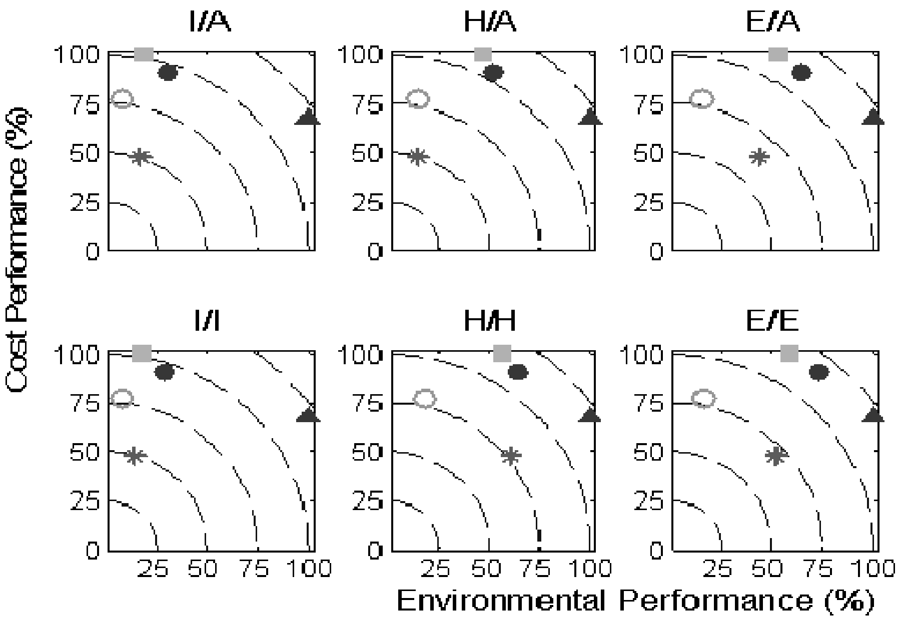

Figure 3: Cost performance vs. environmental performance for the partitions variable (P&CG) (square – silicate block, solid circle – gypsum block, circle – cellular block, triangle – concrete block, asterisk – gypsum board).

6 SUMMARY AND CONCLUSIONS

A full life cycle analysis methodology of an entire building was developed by reducing the number of calculations required for such analysis. A representative unit is defined for the investigated site. The range of possible solutions for each design variable is determined, as well as the maintenance and usage conditions. The solutions are analyzed for their Full Environmental Impact Range (FEIR) for each stage of their life cycle. Three groups were defined: production and construction, maintenance (including renovation, rehabilitation and demolition) and operational energy. The latter was defined as an independent group since the former groups relates mainly to the amount of materials whereas the latter refers to energy for acclimatization and illumination, which involve non-linear parameters such as window size and orientation, thermal mass of elements, etc. It was found that most of the variables can be assigned to one group only, which means that optimization can be performed within this group only, thus reducing the number of required calculations. Only a few variables were assigned to a fourth group, which included variables relevant to more than one of the above groups.

Group allocation was found to be sensitive to the method of energy production but insensitive to methods of recycling. Thus, it can be said that this methodology is sensitive to the geographical location of the building and grouping must be done anew for each different location.

Once grouping has been completed, it is simple to optimize a specific building to minimize its environmental impact and to include other aspects such as economic considerations. The methodology was demonstrated on a typical office building.

7 REFERENCES

Alexander, B., Barton, G., Petrie, J. and Romagnoli, J., 2000, "Process synthesis and optimization tools foe environmental design: methodology and structure", *Computers & Chemical Engineering* **24** 1195-1200.

Becker, R. and Paciuk, M., (2003), "Upgrading energy efficiency, comfort and air quality in an Israel school", in 'Research in Building Physics', Proceedings of the 2nd International Conference on Building Physics, Leuven, Belgium, September (Research in Building Physics, Carmelict, Hens & Vermeir (eds), 2003) 929-935.

Crawley, D., Lawrie, L., Frederic, C., Winkelmann, C., Buhl, W., Huang, Y., Curtis, O., Strand, R., Liesen, R., Fisher, D., Witte, M. and Glazer, J., 2001, "EnergyPlus: creating a new-generation building energy simulation program", *Energy and Building* **33** 319-331

De Langhe, P., Criel, S. and Ceuterick, D., 1998, "Green design of telecom products: The ADSL high speed modem as a case study", *IEEE Transactions on Components Packaging and Manufacturing Technology Part A* **21** (1) 154-167.

Dimson B., (1996), Principles and challenges of sustainable design and construction, *Industry and Environment*, 1(2), pp. 19.

Dobson, I., 1996, "Life cycle assessment for painting processes: Putting the VOC issue in perspective", *Progress in Organic Coating* **27** (1-4) 55-58.

Dones, R. and Frischknecht, R., 1998, "Life-cycle assessment of photovoltaic systems: Results of Swiss studies on energy chains", *Progress in Photovoltaics* **6** (2) 117-125.

Goedkoop, M. and Oele, M., 2001, "Introduction into LCA methodology and practice with SimaPro 5", SimaPro 5.0 User Manual.

Holland, J. H., 1975, "Adaptation in natural and artificial systems", (University of Michigan Press).

Houck, C., Joines, J., and Kay, M., 1995, "A Genetic Algorithm for Function Optimization: A Matlab Implementation", NCSU-IE TR 95-09.

Hwang C-L. and Masud A. in collaboration with Paidy S. and Yoon K., (1979), Multiple objective decision making – methods and applications, Springer-Verlag, Berlin Heidelberg New York.

Kalogirou S. Florides G. and Tassou S., (2002), Energy analysis of buildings employing thermal mass in Cyprus, *Renewable Energy*, 27, 353-368.

Lippiatt, B., 1999, "Selecting cost-effective green building products: BEES approach", Journal of construction engineering and management 448-455.

Petersen, E., 1999, "LCA tool for use in the building industry", *International journal of low energy and sustainable building* **1** 1-11

Shariah, A., Shalabi, B., Rousan, A. and Tashtoush, B., (1998), Effects of absorptance of external surfaces on heating and cooling loads of residential buildings in Jordan, Energy Conversion and Management, 39, pp. 273-284.

Thompson, M., Ellis, R. and Wildavsky, A, 1990, "Cultural Theory", (Westview Print Boulder).

Sustainability assessment of building refurbishing operations

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ABSTRACT: The actual development model that gives priority to demolition and new construction in detriment to building refurbishing is not compatible with the aims and objectives of Sustainable Development. The sustainable building refurbishing embraces an endless list of parameters that should be taken into account by all building stakeholders. The individual analysis of these parameters does not allow verifying which solution has the best trade-off between the several sustainability parameters. The aim of this paper is to present a multi-criteria decision based methodology that allows the integrated assessment of all different parameters. At the end, the methodology is applied to a case study, which aim is to select the most sustainable solution between two different refurbishing solutions for a building façade.

1 INTRODUCTION

Sustainable Development searches the best trade-off between three dimensions: environment, society and economy. Construction and mainly the building sector has great influence in that objective. Buildings accounts for the greatest amount of the total residues production and energy consumption. Besides that, buildings are the population's center of life: an adult in a developed country spends almost 90% of its life inside buildings. Globally, buildings construction is responsible for about 40% of raw materials (stone, gravel, sand, etc), 25% of wood, 40% of energy and 16% of water annually spent all over the world (Roodman, 1995). In Portugal, in spite of existing important differences between the reality and the statistical figures, according to national energy directorate (DGGE) and national statistics institute (INE), during operation phase, buildings (houses and offices) accounts for about 25% of the national primary energy consumption, 6,7% of the total water end-use and is responsible for the annual production of 420 millions of cubic meters of residual water. According to INE, construction industry is also responsible for the annual production of about 7,5 millions tons of solid residues. These figures show that buildings are related with strong environmental, social and economical impacts that have great potentialities to be to some extent overcame.

In Portugal, during the last decade of the 20th century it was possible to assist to a huge growth in the construction market, mainly in new buildings and road infrastructures sectors. For instance, in the second half of the 90's the national construction sector's growth rate was ten times higher, compared to the European average rate. From 1999 to 2002 were built an average of 105 000 new residential units per year. These figures are even more significant if they are compared to the reality of the most developed European countries, where the retrofitting/rehabilitation market assumes a higher relative importance. According to Euroconstruct, the retrofitting/rehabilitation market in Portugal represents about 8% of the total construction works, while the Western European average is nearly 45%.

Despite the fact that in an initial phase this mismatch was justified by the relative underdevelopment of Portugal, this unsustainable growth is raising a set of problems that the construction market is facing nowadays, like p.e., overplus number of residential units built to a stagnated and each day older population, urban planning chaos caused by the disorderly growth, progressive degradation and consequent desertification of urban centres.

Building refurbishing in opposition to demolishing and new construction is an important step towards sustainability. Correcting the actual policy of “use and throwaway” it is possible to overcome some economic problems; to increase the occupants and users comfort; to turn down the environmental impacts through the energy consumption, raw materials and residues reduction; and to preserve the city’s cultural legacy.

Sustainable refurnishing is based in several different aspects, some times contradictory, related among others to the quality of materials, economic impacts, indoor environment comfort, protection of environment, cultural heritage, etc..

Although there still is an important question that must be solved: to define the sustainable refurnishing concept through tangible goals. Sustainability assessment is a holistic approach that doesn’t consider all aspects related to the environmental, economic and social performances of a solution, but only those parameters that better compromises the objectives of the assessment, the type of solution, the available data, among others. The application of the “Sustainable Development” concept is based on the definition of objectives and criteria to be used in the sustainability assessment and comparison of different building solutions. This way it is possible to choose the most sustainable solution, according the considered aspects.

This paper presents the first step for the development of a methodology for the sustainability assessment of building refurnishing processes, which is based in the three dimensions of Sustainable Development. At the end of the paper, the methodology is applied to a case study which aims are the selection of the most sustainable refurnishing solution for a building façade, according to the assessment objectives.

2 SUSTAINABILITY ASSESSMENT METHODOLOGY

The methodology presented in this document is a derivation and adaptation of the Metodology for the Relative Assessment of Building Solutions (MARS-SC) that was developed in order to evaluate new construction solutions (Mateus, 2004). This methodology follows these steps: definition of parameters, quantifications of parameters, normalization of parameters, aggregation of parameters, representation and assessment of the solution.

In the next paragraphs is made a short description of the methodology MARS-SC adapted to refurnishing operations.

2.1 *Definition of parameters*

The sustainability assessment is holistically made, because it is impossible to consider all parameters that express the performance of a solution at the level of the three dimensions of the sustainable development. This way, in this phase the number and type of parameters to be assessed inside each dimension are defined. The definition depends on one hand in all objectives of the assessment, type of solution to be refurnished, local conditions, functional requirements that are necessary to fulfil, available data, and in the other hand in the assessment boundary: the sustainability assessment of a single construction element refurnishing is not based in the same parameters used for a whole building or district. Table 1 presents some parameters that could be considered in a sustainability assessment of a refurnishing solution for a façade.

2.2 *Quantification of parameters*

After selecting the parameters it is necessary to proceed with their quantification. Quantification it is essential to compare different solutions, aggregate parameters and to accurate assess the solution. The quantification method should be anticipated. There are several quantification methods: previous studies results, simulation tools, expert’s opinions, databases processing, etc. (Cherqui, 2004). In some cases times the parameters to evaluate are quantitative. When assessing qualitative parameters like for instance, aesthetics and maintenance aptitude, the qualitative performance level is transformed in a quantitative scale, using the equivalences presented in Table 2.This transformation is based in the comparison of the performance with the best and conventional/minimal normalized performance.

Table 1. Parameters that could be used in the sustainability assessment of refurbishing solutions for building façades.

	Parameters	
Environmental	Social	Economic
Environmental	Airborne sound insulation	Construction cost
Global warming potential	Thermal insulation	Operational cost
Fossil fuel depletion potential	Structural safety	Refurnishing cost
Acidification potential	Fire safety	Dismantling/demolition cost
Chemical oxygen depletion	Water permeability	Residual value
Production of residues	Maintenance aptitude	Residues treatment cost
Embodied water	Preservation of the city's heritage	
Reusing potential	Aesthetics	
Recycling potential		

Table 2. Equivalences between the qualitative and quantitative performances.

Qualitative performance	Score
Best solution	1,00
Good solution	0,75
Slightly better than the conventional solution	0,25
Conventional solution/minimum standard	0,00

It is not easy to evaluate the environmental parameters mentioned above. Although there are some life-cycle inventory (LCI) databases about the environmental pressure related to several construction materials that could be used to support life-cycle analysis (LCA). It is also possible to use LCA tools to evaluate the parameters mentioned above.

To assess the social parameters related to the indoor environment comfort, it is possible to use one of the several normalized methodologies available. Another way is to use and process some available databases that collect common functional performance data related to some conventional refurbishing solutions. Whenever possible, experimental results should be used, because those are the ones that best draw up the real performance of the solution.

Life cycle cost analysis (LCCA) is more straightforward than the environmental performance assessment, since there are different standardized methodologies and published construction costs databases. LCCA is a method that allows the quantification of the global cost of a product for a certain period of service life. In this method all costs are included: construction cost (capital cost), operation cost, maintenance cost and the residual value of the building or of some part of it. LCCA is an important approach whenever it is necessary to compare two solutions that have the same functional requirements but that differ at the level of their initial and operational costs.

2.3 *Normalization of parameters*

The objective of the normalization of parameters is to avoid the scale effects in the aggregation of parameters inside each dimension and to solve the problem that some indicators are of the type "higher is better" and others "lower is better". Normalization is done using the Diaz-Balteiro et al. (2004) Equation.

$$\overline{P_i} = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall_i \qquad (1)$$

In this equation, P_i is the value of ith parameter. P^*_i and P_{*i} are the best and worst value of the ith sustainable parameter.

The normalization in addition to turning dimensionless the value of the parameters considered in the assessment, converts the values into a scale bounded between 0 (worst value) and 1 (best value). This equation is valid for both situations: “higher is better” and “lower is better”.

2.4 *Aggregation*

Sustainability assessment across different fields and involves hundreds of parameters. Each sustainable dimension is characterized by several parameters or indicators. A long list of parameters with their associated values won’t be useful to assess a project. The best solution to overcome this situation is to combine parameters with each other to obtain “global indicators”, allowing assessing the sustainability of each solution at the level of each sustainability dimension.

The complete aggregation method that is used in this methodology is presented in Equation 2.

$$I_j = \sum_{i=1}^{n} w_i . \overline{P_i} \tag{2}$$

The global indicator I_j is the result of the weighting average of all the normalized indicators $\overline{P_i}$.

w_i is the weight of the *i*th parameter. The sum of all weights must be equal to 1.

Equations 3 to 5 present how to aggregate the parameters inside each indicator in order to assess the performance of a solution within each sustainable dimension.

$$I_{Env} = \sum_{i=1}^{n} w_{Env\,i} . \overline{P_{Env\ i}} \text{ , environmental dimension} \tag{3}$$

$$I_{Soc} = \sum_{i=1}^{n} w_{Soc\,i} . \overline{P_{Soc\ i}} \text{ , societal dimension} \tag{4}$$

$$I_{Eco} = \overline{P_{Eco\ i}} \text{ , economic dimension} \tag{5}$$

In the economic dimension, the global indicator as the same value of the normalized economic parameter because the normalized parameter results from the sum of every cost found in the life-cycle costing analysis.

The weight of each parameter in the assessment of every indicator is not consensual, as it is possible to verify when analysing the several different available methodologies for sustainable design assessment and support. This is the major inconvenient of this method, when compared to performance based methodologies, since it is possible the compensation between parameters.

Weights are strongly linked to the objectives of the project: higher weights must be adopted for parameters of major importance in the project.

At the level of the weights of the environmental parameters, there are some international accepted studies that allow an almost clear definition. One of the most accepted studies is the one performed by the EPA’s Science Advisory Board (SAB) that developed lists of relative importance of various environmental impacts to help EPA to best allocate its recourses (EPA, 2000).

Whenever there isn’t a local or regional available data, it is suggested to use EPA’s weights in MARS-SC.

In spite of being easy to quantify the functional parameters, the way as each parameter influences the functional performance and therefore the sustainability isn’t consensual. This assessment involves subjective rating and depends, above all, on the type of solution and on the valuator’s social-cultural and economic status. This way in a first approach the methodology considers the same weight for all functional parameters. The MARS-SC is being developed in order to accommodate a more consensual distribution of weights.

2.5 *Representation and assessment of the solutions*

One important feature of the methodology is the graphical representation for the monitoring of the different solutions that are analyzed. The representation is global, involving all the considered objectives.

The tool that is used to graphically integrate and monitor the different parameters is the "radar" or Amoeba diagram. This diagram has the same number of rays as the number of parameters under analysis and is called the sustainable profile. In each sustainable profile the global performance of a solution is monitored and compared with the performance of the reference solution. Furthest to the center is the solution, better it is. It is also possible to verify the solution that best compromises the different parameters used in the assessment.

After assessing the performance of a solution within all dimensions (environmental, societal and economics), the next step is to combine the global scores with each other in order to obtain the sustainable score. Sustainable score (SS) is a single index that resumes the global performance of a solution. As nearest to 1 is the sustainable score, more sustainable is the solution. The aggregation method used to calculate the sustainable score is presented in equation 6.

$$SS = I_{Env}.w_{Env} + I_{Soc}.w_{Soc} + I_{Eco}.w_{Eco} \qquad (6)$$

Sustainable score, *SS* is the result of the weighting average of each global indicator I_j. w_i represents the weight of the *j*th parameter.

The weight of each dimension in the global sustainability is still not consensual. It depends, among other, in the objectives of the project and local priorities. In MARS-SC it is proposed to use the weights presented in Table 3.

Table 3. Weight of each sustainable dimension in the sustainable score assessment.

Indicator	Weight (w_i)
Environmental (I_{Env})	0,30
Societal (I_{Soc})	0,50
Economic (I_{Eco})	0,20

The *SS* value should not be singly used in order to characterize the sustainability of a solution, since it is possible the compensation between dimensions and moreover the solution has to be the best compromise between all the different aspects: every aspect has to be represented.

3 CASE STUDY

The scope of the case study is the assessment of a refurnishing project related to a multi-storey building with three floors, located in the city's centre of Guimarães. This building was built at the end of the 60's and most of its envelope, mainly the façade, is in a considerable degradation state (figure 1). This building doesn't have any king of heritage value. In the façade it is possible to identify some cracks that are compromising the water permeability of this construction element. The aim of this project is not only to improve the building aesthetics, but also to improve other functional characteristics, mainly the thermal comfort, in order to turn it compatible to the actual comfort demands. Another requirement to fulfil is that the refurnishing solution should be the best compromise between the three dimensions of sustainable development.

After examining the façade it was possible to conclude that the cracks are stable and that the original solution used in the façade is a hollow brick cavity wall without any insulation material, as presented in Figure 2.

The refurnishing solution to adopt should not disturb the indoor living conditions of the inhabitants. This way the two solutions proposed for the façade's opaque area were the ventilated façade (solution 1) and the external thermal composite system – ETICS (solution 2). The cross-section of both refurnishing solutions are presented in Figures 3 and 4.

In order to fulfil the thermal standard valid during the design period (Decrew-Law 40/90) it was necessary to reduce the U-value of the façade in 42%, in relation to the initial value.

Figure 1. Elevation of the façade.

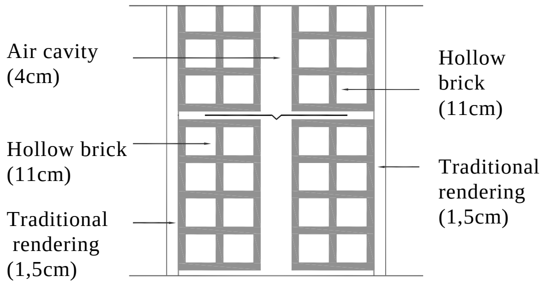

Figure 2. Cross-section of the existing solution.

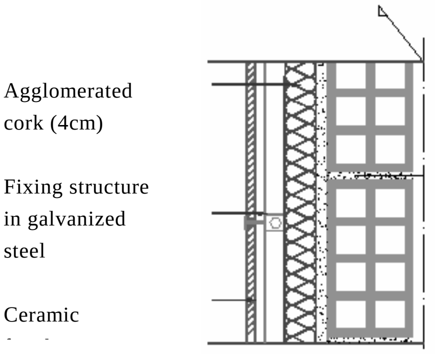

Figure 3. Refurnished façade's cross section after (solution 1).

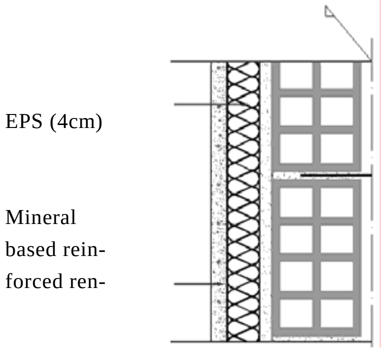

Figure 4. Refurnished façade's cross section after (solution 2).

3.1 *Accessed parameters and related weight*

At the level of the environmental performance, the project team decided that the solution to adopt should have the lowest possible embodied environmental impact. The selected parameters for the environmental performance assessment were: embodied primary energy (PEC), global warming potential (GWP), habitat alteration (HA) - based on the construction mass (M) and quantity of residues produced during materials processing (R), acidification potential (AP) and chemical oxygen depletion (COD).

In which regards to societal performance, the aim was to find the best compromise between the following functional parameters: airborne sound insulation ($D_{n,w}$), U-value (U), maintenance aptitude (MA).

For the economic performance the aim was to choose the solution with lower construction cost. This way it was considered just one economic parameter in the assessment: construction cost (CC).

Table 4 resumes the considered parameters and related weights.

Table 4. Assessed parameters and related weight.

Dimensions	Parameter	Parameter's Weight (%)	Dimension's Weight (%)
Environment	Primary energy consumption (PEC)	11,1	30,0
	Global warming potential (GWP)	33,3	
	Habitat alteration (HA)	33,3	
	Acidification potential (AP)	11,1	
	Chemical oxygen depletion (COD)	11,1	
Societal	Airborne sound insulation ($D_{n,w}$)	33,3	50,0
	U-value (U)	33,3	
	Maintenance aptitude (MA)	33,3	
Economic	Construction cost (CC)	1,00	20,0

3.2 *Quantification of parameters*

Besides the environmental performance of both refurnishing solutions, Table 5 presents, only for information, the environmental performance of the initial solution. In Portugal is not available LCI data related to the building materials' environmental impacts. This way the results are based in the values presented by Berge for Central Europe (Berge, 2000)

Table 5. Environmental performance of the initial and both refurnishing solutions.

Solutions	M(1) Kg/m^2	PEC(2) kWh/m^2	GWP(3) g*10^3/m^2	AP(4) g*10^3/m^2	COD(5) g*10^3/m^2	R(6) g*10^3/m^2
Initial	244,05	161,56	39,51	0,40	3,70	15,72
Solution 1	29,60	83,10	14,63	0,13	5,18	3,17
Solution 2	43,00	32,59	5,77	0,04	0,46	0,71

(1) Total construction mass per square meter.
(2) Embodied primary energy.
(3) Global warming potential in CO_2 grams equivalents.
(4) Acidification potential in SO_2 grams equivalents.
(5) Chemical oxygen depletion in NO_x grams equivalents.
(6) Residues that result from the production of the construction materials.

Table 6 presents the results found in the functional and economic performance assessment of both solutions. In order to compare between the initial and refurnished performances, the initial performance is also presented. The construction costs are based in a cost estimation drawn up by three construction companies which head-office is situated in the North of Portugal. They include all direct and indirect costs and profits related to construction works.

Table 6. Functional and economic performances of the initial and both refurnishing solutions.

Solutions	U W/m^2.ºC	$D_{n,w}$ dB	CC €/m^2
Initial	1,40	45	-
Solution 1	0,60	48	100
Solution 2	0,60	46	35

3.3 *Representation and assessment of both solutions*

Table 7 resumes the results found in the sustainability assessment of both refurnishing solutions, using the methodology MARS-SC. Figure 5 presents the sustainable profile of both solutions. Analyzing the results it is possible to observe that refurnishing solution 1 is only better than solution 2 at the level of the functional requirements. This reality is based on the major advantages of this solution: high maintenance aptitude and improved airborne sound insulation. The use of ceramic materials and galvanized steel, two materials that have high embodied energy, turns the environmental performance lower than the ETICS refurnishing solution. Another important drawback of this solution is the high construction cost, almost 285% higher than the solution 2 cost.

This way, in the analysed sample and according to the considered dimensions, parameters and related weights, the most sustainable refurnishing solution is the external thermal insulation composite system – ETICS (solution 2).

Table 7. Results obtained in MARS-SC

Solutions	Performance			
	Environmental I_{Env}	Societal I_{Soc}	Economical I_{Eco}	Sustainable Score SS
Solution 1	0,17	1,00	0,00	0,55
Solution 2	0,83	0,33	1,00	0,61

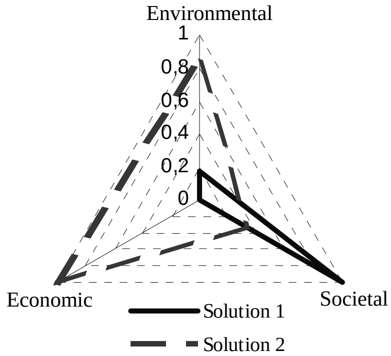

Figure 5. Sustainable profile of both refurnishing solutions

4 CONCLUSIONS

Sustainable building design, construction, operation and refurnishing are based in the assessment of the environmental pressure, societal performance (related to the construction norms, regulations and psycho-social characteristics of building's users, among others) and life-cycle costs. Sustainable construction seeks a better compatibility between natural and artificial environments, nevertheless without giving up the buildings' functional quality and the project's cost-effectiveness.

The rehabilitation of the building stock is an very important aspect in order to increase the sustainability of the construction market: in one hand refurnishing increases the durability of the construction elements, which allows the amortization of the initial environmental impacts in an extended life span, and in other hand, it allows to update the buildings' functional performance, with all societal and cultural advantages, along with the exploitation of the existing structures, with every related economical advantages.

Despite of several studies about sustainable construction indicators, up till now there wasn't a methodology that could assist the project team in the sustainable refurnishing projects. In this paper it was presented a methodology to assess the sustainability of the building refurnishing projects. There are still some important limitations to overcome, like for instance the development of a more consensual list of weights. Although at this step, the methodology could give an important input to project teams in order to turn the refurnishing operations much more compatible to the sustainable development aims, in order that the future generations coould have at least the some conditions as the actual ones.

5 REFERENCES

Berge, B. 2000. Ecology of building materials. Traduction from the original Norwegian title "Bygnings materialenes okologi". 1ª Ed. Oxford: Architectural Press.

Cherqui, F. & Wurtz, E & Allard, F. 2004. Elaboration d'une méthodologie d'aménagement durable d'un quartier. Annales du bâtiment et des travaux publics. 1ª Ed. Pág. 38-34.

Diaz-Balteiro L.& Romero C. 2004. In search of a natural systems sustainability index. Ecological Economics; 49, pp 401-405.

EPA. 2000. Toward Integrated Environmental Decision-Making. United States Environmental Protection Agency, Science Advisory Board, EPA-SAB-EC-00-011, Washington, D.C., August and United States Environmental Protection Agency & Science Advisory Board. Reducing Risk: Setting Priorities and Strategies for Environmental Protection, SAB-EC-90-021, Washington, D.C., September, pp 13-14.

Mateus, R. 2004. Novas Tecnologias Construtivas Com Vista à Sustentabilidade da Construção. MsC Thesis, Department of Civil Engineering, University of Minho.

Roodman, D.M.& Lenssen, N.1995. A Building Revolution: How Ecology and Health Concerns are Transforming Construction. Worldwatch Paper 124, Worldwatch Institute, Washington DC, March, 1995.

The Portuguese LiderA System – From Assessment to Sustainable Management?

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ABSTRACT: LiderA is a voluntary Portuguese system that intends to assess the sustainable buildings. It is been in development since 2003 and this year it certified the first five Portuguese buildings. Besides a brief explanation of LiderA approach and certification cases, this paper presents other possible applications of this assessment system, in order to lead environmental management in building to sustainable management.

1 LIDERA – PORTUGUESE ENVIRONMENTAL BUILDING ASSESSMENT SYSTEM

Sustainable development, sustainable construction or buildings can have a broad perspective, from triple bottom to strong sustainability. In all them, the environment must have an important role with minor or major perspective from economics, social or other components (Kibert 1994; Kibert 2003).

LiderA (in Portuguese the acronym for environmental leadership to sustainable construction) is a voluntary system to assess the sustainable Portuguese buildings that is been in development since 2003 (Pinheiro and Correia, 2005), and is mainly based in environmental dimensions.

The LiderA sustainable assessment have its core in environmental components, like soil and integration, resources (energy, water and materials) and environmental loads, complemented with social aspects like comfort, accessibility, and technical components like durability, environmental management and innovation.

The system have a top-down approach with 6 categories, divided in areas (21) and subsequently in criteria (50) in order to allow in those, the nesting of different levels of detail and analysis. The global set of criteria can be applied to different uses with different thresholds to define levels of sustainable performance. Levels range from G to A++, in which A level means 50 % of improvement towards practice (usual E level) and A+ and A++ an improvement Factor 4 and Factor 10.

To be certified, LiderA system must verify that it complies with legislation and have a performance that achieve at least a C level. The first five certificated buildings appeared in 2007 and are (name, data of use, use type, built area):

- Hotel Jardim Atlantico (Calheta), 1993, tourist complex, 7 497,20 m^2, 97 apartments;
- Torre Verde (Lisbon), 1998, one residential building, 7 200 m^2, 41 apartments;
- Casa Oásis, (Faro), 2002, one tourist house, 240 m^2;
- Ponte da Pedra, phase 2 (Matosinhos), 2006, two residential buildings, 14 852 m^2, 101 apartments;
- Parque Oriente (Lisbon), design phase approved, 13 buildings, 41 441 m^2, including a residential area (27 912 m^2) with 185 apartments and different types of commercial use in other areas.

The assessment and certifications involve 72 230 m^2 in residential (70 %), tourist (11%) and commercial use (19%), from a house to several buildings, in design and operation phases, showing that it is possible to have multi-application to different types of buildings.

In the certification cases range from energy performance, thermal comfort and other areas and different levels between apartments, once they have different orientations and conditions, what point out to the need of adjust in project, in order to assure similar levels. This emphasises the possibility of scale and adjust.

2 FROM ASSESSMENT TO MANAGEMENT

Nevertheless, the environmental performance of the buildings depends not only of the design but also of the type of use and management as Ratti (*et al.*, 2005) point out to the case of energy in offices. In an analysis of near 100 office buildings the authors show that energy consumption could have a variation of 1 to 20, where a factor of 2 results from the users of the offices (2,5 factor from design, 2 factor from the system and 2 factor from urban context). In other areas like water, solid wastes, energy consumption in transports, the users could have a larger influence.

So, in order to walk to sustainable buildings, it is need to achieve a higher environmental performance at buildings, that include good environmental design, and tools to assess and certify, but also the support by the user and management with environmental management knowledge and capabilities, like an environmental management system to support the use phase and complementarily in the construction phase (new, renovation or demolition).

The most used international environmental management system (EMS) is ISO 14001 (Block, 2006:8; Peglau 2002; Kein *et al.*, 1999:449) and it can be an important tool to the construction sector (Ball, 2002) and to buildings (Hill e Bowen, 1997).

The application of ISO 14001 can contribute to achieve a better environmental performance and perhaps to contribute to sustainable buildings. That challenges the ISO 14001 in several dimensions:

1. ISO 14001 is a base to improve organization and can be neutral, since it is not focused in a specific level of environmental performance, and so the practical results are not necessarily a more sustainable organization or building. In order to assure that environmental performance is achieved, assessment tools will be need;
2. ISO 14001 is design to command and control and in cases of buildings environmental management, the users can be informed and influenced but command is not necessarily a good approach, so the logic must be to adjust in order to inform and influence several stakeholders;
3. ISO 14001 can be applied to different phases, from the idea, to construction, operation and demolition or deconstruction, but usually it is applied to a specific phase, in most of the cases in construction and partially in operational phase, and do not interlink information and management between phases, which constitutes an important step;
4. ISO 14001 requires specific formal procedures which must be adjust depending of the phases, uses types, for example the applications in construction phase can demand for the need of simpler formal approach and in the operation of a hotel can call for further formal strategies.

The environmental performance focus is the base to drive from environmental management to sustainable management. As Hill and Bowen (1997) indicated, integrated environmental assessment tools with environmental management can be a base to search and implement sustainability.

Since the performance of the buildings result from several aspects and in most of the cases is important to create conditions to improve and manage, the assessment can give a structural input to that approach.

LiderA assessment can be done in the several phases, and it can assess for example in operation phase, measuring the standard use (in average behaviour from the users and maintenance) of the building with the LiderA thresholds level; so when compared with the real performance, that gives a margin to the users, management, and maintenance to further improvement.

In that context, one of the possible applications of results is to interlink with a potential environmental management system (ISO 14001) with specific requires deriving from the assessment component and expanded it to complementary aspects, from social and economics areas. This approach in which the assessment component supports the future use and management of the buildings can lead to new performance and continuous improvement.

3 CAN LIDERA SUPPORT SUSTAINABLE MANAGEMENT?

Usually (Cole, 1998) the assessment system are developed in specific phases (to assess design or operation), types (residential, offices, or others), context (most of them area bottom up), and so applications in broader context can be difficult.

Theoretically, LiderA approach with a hierarchical level, and a structural approach, allows other applications and since it is focused at environmental performance it can be used to support EMS (like ISO 14001) to sustainable management. What happens in practice?

When we analyse the five LiderA certifications, four of them have components from environmental management, like environmental information and monitoring and Hotel Jardim Atlântico have a full ISO 14001 certification.

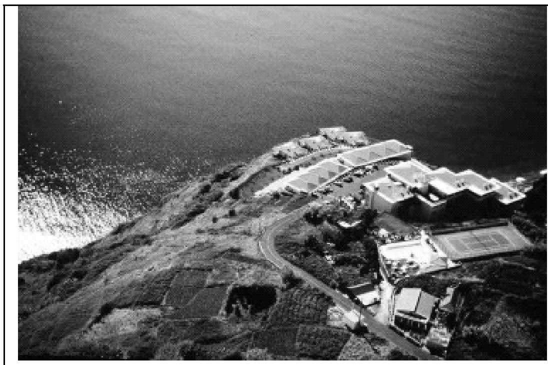
Hotel Jardim Atlântico (four stars hotel), it is located in Portugal, Madeira Island, in a place called Calheta. Since it was built in 1993, the focus of the approach and services is based on the idea of Nature, aiming to be integrated in the landscape and defending the environment (HJA, 2007). The Hotel has an implantation area of 19.808 m2 with a garden area of 25.000 m2.

The building design was careful about the landscape, use of bioclimatic principles and also solutions allowing reducing the consumption of resources, like energy and water, and reducing, treat and reuse environmental loads, like effluent discharge or solid waste.

Nevertheless, the environmental performance depends not only of the design but also of the type of use and management. They adopted an ISO 14001 System as a component to define its policy, environmental program and practical measures that involve the workers and the users. They implemented an environmental program (including measures and management actions) in the following areas:

- Landscape impact - e.g: The hotel was efficiently planned and built in order to integrate the buildings in the landscape; they have built an own typical footpath near the hotel in the middle of unspoilt nature. The hotel installed clotheslines on the balconies to prevent the guests drying their towels over it.
- Energy efficiency – e.g.: Key switches in the guest rooms; use of energy efficient light bulbs; most apparatus and machines are equipped with low consumption and recovery energy equipment; good isolations in every part in order to avoid loosing energy; The laundry uses digital measuring apparatus and exact computerized programs to obtain an exact capacity and lower consumption of water and energy; they have checklists, where they check every day, weekly or monthly, all the maintenance of the house to have a control and a prevention policy.
- Management of fresh water resources - e.g.: They have installed water savers in all taps; apply to the guests to save water, for the well being of our nature; provide instructions on how to use the toilet flush, depending on the necessity of everyone, in order to reduce again 50% of water. At the same time they reduce the water capacity of the reservoir to a minimum, saving 40% at each flush; in the laundry, for the steam iron, they use the recycled water from the dehumidifying machine.
- Waste water treatment - e.g.: They have a biological cesspool (sewage) and they use the treated water for the irrigation of the garden in order to save the fresh water; the irrigation water from the cesspool is rich in manure, so they don't need fertilizer or other ecological harmful products; they kept a planed cleansing of the small water courses "levadas", watercourses, siphon, etc… for a better drain in case of rain, as prevention;
- Air quality and noise control - e.g.: All rooms have natural ventilation and no air conditioning; periodically they check and clean the chillers and air conditionings (public areas);
- Employees, guests and public entity's - e.g.: They have trained the employees through initiatives about their environmental policy; they inform the guests about the environmental programs and activities. 90% of guests participate and give new sug-

gestions/ideas. Some of them have already been implemented; the municipality and other public entities cooperate.



a) Panoramic View

b) Hotel with gardens irrigated with treated wastewater

c) Lamps of low energy consumption

d) Rain Water collection

e) Low water consumption taps

f) Waste Water Treatment

Figure 1 – Hotel Jardim Atlantico – Example of environmental measures

The environmental management system and its performance is periodically monitored and annually revised with a general balance and assessment of objectives and goals. The results show progressive advances (e.g. between 2005 and 2006 the package reduction approach lead to a reduction of 18 % in waste), improvement opportunities and aspects that are worst. Deriving from that annual balance usually it is designed the next year action program, in order to have a better performance.

Nevertheless this assessment is relative and does not allow a full view of the situation and the building's environmental performance level. The HJA LiderA assessment (Pinheiro, 2007) show the Hotel with a position of good environmental performance (Figure 2) in areas like energy and water, effluents, solid, indoor air quality, or thermal comfort.

Local and integration	
3	**Landscape**
C5	Local integration (C LiderA level)
4	**Amenities**
C7	Valorisation (B)
Resources	
6	**Energy**
C11	Electricity consumption (B)
C15	Equipment efficiency (A)
7	**Water**
C16	Domestic water use (B)
C19	Rainwater collection and use (C)
C20	Storm water management (B)
Environmental Loadings	
9	**Effluents**
C25	Wastewater production (B)
C26	Wastewater treatment (A)
C27	Wastewater recycling (A)
10	**Solid Waste**
C31	Waste production (C)
C32	Toxic waste (C)
C33	Waste recycling (A)
13	**Thermal Effects**
C35	Heat Island (C)
Interior Environment	
14	**Indoor environmental air quality**
C36	Natural ventilation (C)
C38	Micro contaminant prevention (B)
15	**Thermal comfort**
C39	Adaptative comfort (A)
Durability and Accessibility	
20	**Accessibility**
C47	Relations with the community (C)
Environmental Management and Innovation	
21	**Environmental Management**
C48	Environmental Information (A)
C49	Recognize Environmental Management System

Figure 2 – Hotel Jardim LiderA Profile Assessment Level (Pinheiro, 2007)

LiderA assessment shows that HJA have a better environmental performance when compared with other same level of services hotels. For example, in 2006 (HJA, 2007b) when compared with an average of 4 star Hotels in Madeira, the average shows a:

• 67% reduction in consumption of electricity by night and by user;
• 22% reduction in propane gas by night and by user;
• 55 % reduction in water consumption by night and by user.

The LiderA does not give only an indication of improvement face to the average practice, but once the limit of improvement is not A (50 %), but factor 4 or 10 (respectively A+ and A++) it point out structural areas of improvement. For example, they have a system to collect the rain water that can be use to supply swimming pool and to other uses, reducing the needs of potable water to level 75 % compared with practice, or to include solar panel to heating the waters. These will imply small construction works. Other aspects, like reducing toxic waste will imply further supplier involvement and personal training, in order to reduce to 75 %.

The role of LiderA assessment can be used as a global view, making a contribution to identify new environmental aspects and give new performance goals in short, medium and long term in the way to sustainability.

From other perspective, the role of environmental management in HJA could lead to a better environmental performance and to a continuous dynamic, which can also support a higher sustainable building performance.

In others cases, like Torre Verde, Casa Oasis, Ponte da Pedra or Parque Oriente the situation is that they do not have a full EMS, but they have or will have at least an user's manual, a maintenance manual and ways to inform (internal web site, newsletter, reports, meetings or others) the building management and the users of the environmental level, allowing them to make better decisions and improve global or individual actions.

Figure 3 – Torre Verde Environmental building manual (Tirone Nunes, 2005)

4 ENVIRONMENTAL BUILDING ASSESSMENT AND ENVIRONMENTAL MANAGEMENT

The main question is to know that if it exist a positive relation between these two approaches. The HJA show that complementary it can exist and it has a positive relation leading to a better environmental performance, but it also shows the existence of some critical points. There is different focus and application in different phases.

Traditionally, to each area it is applied a specific context, and in specific phases this can be a fragmenting trap, so assessment and management must be defined since, as LiderA pointed out, the earlier phases of the project and support all the life cycle phases like construction, operation and demolition or deconstruction.

Another important aspect is that most of the important decisions are taken in earlier moments and in phases where the environmental information is reduced and it is difficult to have an integral performance assessment. So a possible prescriptive orientation and assessment is essential in preliminary phases, as presented in LiderA system to that specific phase.

As Cole (*et al.* 2005), point out several possibilities can be postulated regarding the possible ways that assessment methods may evolve in the longer future including: assessment methods will need to be cast within a broader array of initiatives for creating necessary change, will have to be recast under the umbrella of sustainability – environmental, social and economic.

In most of the cases in assessment methods, economic or cost analysis are implicit (or absence) but not explicit and are partial. An exception is GB Tool, which included that approach (Larson, 1999) and that is a reason why LiderA component recommend a life cost cycle analysis.

The environmental management system includes mainly the workers and suppliers. In order to go towards sustainable management the system must be enlarged and must include the users and other stakeholders, even in an influential context.

LiderA system provides an assessment of environmental performance, not only related with the improvement of practice but to further structural improvement that can give, as showed, a broader view from environmental performance to sustainable level. LiderA have also specific criteria to environmental management information and environmental management system.

Nevertheless it is important and needed to include new degrees of action and management in the buildings in order to allow a dynamic management in different moments and with different users. So, as LiderA points out, there is a need to consider environmental management aspects in the design phase.

LiderA can be the base to interlink an environmental building assessment with an environmental management system (like ISO 14001, that must be adjusted), focusing in environmental performance and applied at different phases, creating, in theory and practice, a win-win relations between these two approaches.

5 CONCLUSIONS

LiderA is a voluntary Portuguese system to assess the sustainable buildings that begins to be in the market in an experimental phase, but certified in 2007 the first five buildings, involving 72 230 m^2 in residential (70 %), tourist (11%) and commercial uses (19%), from a house to several buildings, in design and operation phases.

These five certifications show that it is possible to have a multi-application to different types of buildings and to several life phases, resulting from the top down structure with different levels of detail and thresholds linking design, construction, use and final end life.

Besides the usual assessment system, the hotel Jardim Atlantico case point out that it is possible and needed a potential positive relation between environmental management system and LiderA system.

Since the final performance depend from several components, including design and users, the two approach can be complementary and can create a win-win relation if they use the environmental assessment system as a base to implement a full strategy to ensure environmental and sustainable performance with broader view, environmental performance focus, and adjust from environmental management system.

In conclusion, another new frontier to sustainable environmental assessment is a holistic approach that links the sustainable assessment component to the environmental management system (mainly users) in order to achieve higher sustainable performance.

As Cole (*et al.* 2005) explains market-based assessment methods will have to reinvent themselves to maintain potency. To that field, LiderA system could provides new perspectives, experimental applications, creating new opportunities and challenges.

6 REFERENCES

- Ball, Jonathan (2002). Can ISO 14000 and eco-labelling turn the construction industry green? Building and Environment, Volume 37, Issue 4, April 2002, Pages 421-428

- Block, Marilyn (1999). Identifying Environmental Aspects and Impacts. ASQ Quality Press, 145 p.

- Cole, Raymond J. (1998). Emerging trends in building environmental assessment methods. Building Research & Information, Volume 26, Number 1 / January 1, 1998, 3 - 16 p.

- Cole, Raymond J; Howard, Nigel; Ikaga, Toshiharu; Nibel, Sylviane, (2004), Environmental Assessment Tools: Current and Future Roles, SB 05, Issue Paper 4 & 5, Tokyo, Japan.

- Hill, Richard C.; Bowen, Paul A. (1997). Sustainable construction: principles and a framework for attainment. Construction Management & Economics, Volume 15, Number 3 / May 1, 1997, Pages: 223 – 239.

- HJA - HOTEL JARDIM ATLÂNTICO (2007a). Main Characteristics. Calheta, Madeira, Portugal, http://www.jardimatlantico.com/ingles/localizacao.html

- HJA - HOTEL JARDIM ATLÂNTICO (2007b) Environmental Management System Report Status 2006. Calheta, Madeira, Portugal, 32 p.

- Kein, Alan; Ofori, George; Briffett, Clive (1999). ISO 14000: Its relevance to the construction industry of Singapore and its potential as the next industry milestone. Construction Management & Economics, Volume 17, Number 4 / July 1, 1999, 449 - 461 p.

- Kibert, C. J. (1994). Establishing Principles and a Model for Sustainable Construction. Proceedings of the First International Conference on Sustainable Construction, November 6-9, 1-10, Tampa, Florida.

- Kibert, Charles (2003). Sustainable Construction at the Start of the 21st Century, International e-Journal Construction, Special Issue - The Future of Sustainable Construction 2003, http://www.bcn.ufl.edu/iejc/pindex/si/10/

- Larsson, Nils K. (1999). Development of a building performance rating and labelling system in Canada. Building Research & Information, Volume 27, Number 4-5 / July 1, 1999, 332 - 341 p.

- Peglau, Reinhard (2002). Applauding the success of ISO 14001 should not deafen us to the challenges. ISO Management Systems – January-February 2002, 15:16

- Pinheiro, M. D.; Correia, F. N. (2005). LiderA - Portuguese voluntary sustainable assessment building system (main lines).The 2005 Sustainable Building Conference in Tokyo 27-29 September (SB05 Tokyo), 2005, Tokyo, Japan.

- Pinheiro, M. D. (2007). LiderA - Portuguese voluntary sustainable assessment building system certification cases. http://www.lidera.info/Casos_ingles.html

- Ratti, C.; Baker, N.; Steemers, K. (2005). Energy consumption and urban texture. Energy and Buildings, Volume 37, Issue 7, 1 762-776.

- Tirone Nunes (2005). Manual de Utilização da Torre Verde, 37 p. Tirone e Nunes, Lisboa

Life cycle assessment of steel and reinforced concrete structures: A new analysis tool

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ABSTRACT: In this paper is discussed the life cycle of steel and reinforced concrete structures using a simplified life cycle analysis. The developed methodology consisted in quantification of a series of parameters both economic and environmental that characterize both reinforced concrete and metallic structures. The parameters obtained are a result of an ongoing investigation in civil engineering companies in Portugal. Based in the life cycle analysis, five parameters were selected in order to make the assessment, in witch: energy consumption, water, CO_2, SO_2, NO_x. A database was developed into a software program that can perform life cycle analysis of these types of structures giving their physical properties. Furthermore, the software was developed in a way that can be used with other types of materials and can be upgradeable in the future in order to expand the number of parameters in analysis. As a result the software outputs the total amount of emissions caused by the production of a given structural element as well as determines the structural costs giving in the end a global project analysis.

1 INTRODUCTION

The concept of sustained development, defined in the Brundtland report in 1987, is a very complex and dynamical challenge that demands contributions of the most diverse activity sectors.

In 1996 the document named “The Habitat Agenda” written in the II Habitat conference that occurred in Istanbul mentions problems related with human communities and specifically refers the participation of the construction industry in the sustained development:

“…encourage the development of methods that are economically and environmentally sane, as well as in the production and distribution of the materials used in construction, including the strengthening of the industries of traditional construction materials that use raw materials that are available as close as possible”

This declaration shows the significance of the construction industry in a sustained development, because this economical activity influences the environment and the well fare of the population as it contributes to the dissipation of the natural resources, energy consumption, air pollution and the creation of waste.

In civil engineering construction, we should have present the life cycle assessment while we select the materials in order to valuate the whole environmental impacts that are directly associated. In order to accomplish reliable results, we should not only define criterions or requests, but also establish a methodology of valuation and environmental characterization of materials in analysis.

In the international scenario, the responsible entities have been present. Between them we have the International Organization of Standardization, in which the ISO 14000 norm as become one of the most relevant tools in the environmental managing. The application models of Life Cycle Assessment (LCA) for selection of construction materials constitutes, at present, a more complete methodology, bounding the materials selection with a global environmental performance (e.g. environmental impacts). The Life Cycle Assessment follows four basic steps, in which step can consist in one or two phases as can be seen in fig.1.

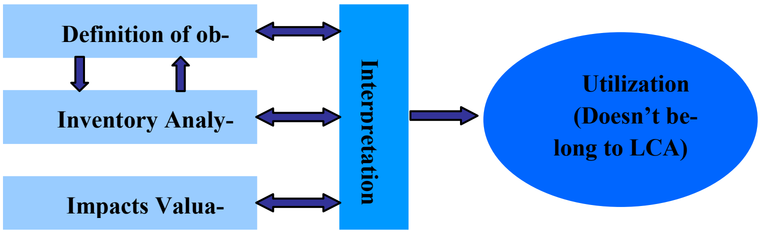

Figure 1 – Scheme of the Life Cycle Assessment phases.

Currently there are no software tools available to help decision makers assess in direct manner energy consumption, water, CO_2, SO_2 and NO_x values regarding the construction of a building. The need for such tools has resulted in the environmental deterioration and the need of quantification of such parameters. The application of this tool will enable decision makers to better manage the LCA of a building by developing appropriate control measures to minimise these risks by, for example, prioritising their operational maintenance strategies.

In this study we've focused on the environmental impacts caused by the manufacturing and transport of necessary materials to build a reinforced concrete or a steel structure. The final results allowed us to decide which structure is more sustainable financially and environmentally. To do so, a software program was developed that allows a Life Cycle Assessment of the parameters earlier referred of any kind of structure. All collected data was inserted in the database program regarding Portuguese parameters in order to create a more accurate simulation.

2 EXPERIMENTAL WORK

The structure's LCA was based in the existing values of the most significant emissions produced in the extraction, production and transformation of the materials used in the conception of the structure. The water consumption and the energy consumption were also considered. The next step was to make a discrimination of the reinforced concrete into its constituents: cement, aggregates, steel bars and wood (formwork). In order the results to be representative of the building construction in Portugal, we've made a campaign in the Portuguese industry that operates in civil engineering construction and sells the raw materials used in the building construction. The data referring to the materials used in reinforced concrete was made available by Cimpor S.A (1) for the cement type used and Siderurgia Nacional (3) facilitated the values for the steel bars. In the aggregates case, the parameters were gathered from an aggregate manufacturing factory (2) and the data used for the formwork (wood) was obtained in the publication CIMAD (4). Regarding the structural steel and because there aren't any industry operating in Portugal, we had to use data from a Spanish company named Arcelor (5) and located in Madrid.

The selection of the several ambiental parameters to be compared was based on the significance of these in ambiental impact terms. The issue of the concordance between the parameters that were given by the companies above mentioned was also considered. It is strictly necessary that all of the several materials have the same parameters. Only so we can make a proper analysis. Once all the data were converted to the unitary value it was possible to estimate the value of the environmental impact caused by the materials in study. Each impact was represented graphically.

Table 1- Environmental parameters relative to the production of reinforced concrete

	Cement		Aggregate		Water		Steel		Wood	
Energy Consumption	2,9	GJ/ton	0,01	GJ/ton	0		1,872	GJ/t	0,306	GJ/m^3
Water	0,18	m^3/ton	0	m^3/ton	0,5	m^3/m^3	0,66	m^3/t	0	m^3/m^3
CO_2	675	Kg/ton	0	Kg/ton	0		0,036	t/t	0	t/m^3
SO_2	0,15	Kg/ton	0	Kg/ton	0		0,005	t/t	0	t/m^3
NOx	2	Kg/ton	0	Kg/ton	0		0,001	t/t	0	t/m^3

We've considered in the energy consumption values, an average standard from Central Europe (6) because measurements are yet to be made for Portugal. Also taken in consideration in this work were the ambiental impacts caused by the transport of steel to Portugal (6). As such, we have estimated the distance between Guimarães (place were the building is found) and Madrid (location of the factory) resulting in an impact due to the transportation based on the weight of the transported steel and the distance between cities added the corresponding emission value per unit of distance due to the emissions produced by the engine of the truck (table 3). The total environmental impact is given by the sum of the production of the steel and its transportation.

Table 2– Environmental parameters of structural steel production

	Value	
Energy Consumption	10	GJ/t
Water	6,6	m^3/t
CO_2	1,51	t/t
SO_2	0,0011	t/t
NOx	0,001	t/t

Table 3– Environmental parameters of structural steel transportation

	Value g/(ton.km)	Distance(km)
CO_2	120	700
SO_2	0,1	
NOx	1,9	

After collecting all values regarding the parameters in issue, a software tool named EcoBuild was developed in Visual Basic. The first step when running EcoBuild was to load the database entries with those presented in tables 1-3, the built in database is very dynamic so it can be easily upgradeable for future works.

The valuation of the ambiental impact of the building materials was made by studying a usual building located in the city of Guimarães. A representative portico of the building (fig.2c) was used in order to assess construction materials of the reinforced concrete structure and then a comparison is made with an equivalent steel portico.

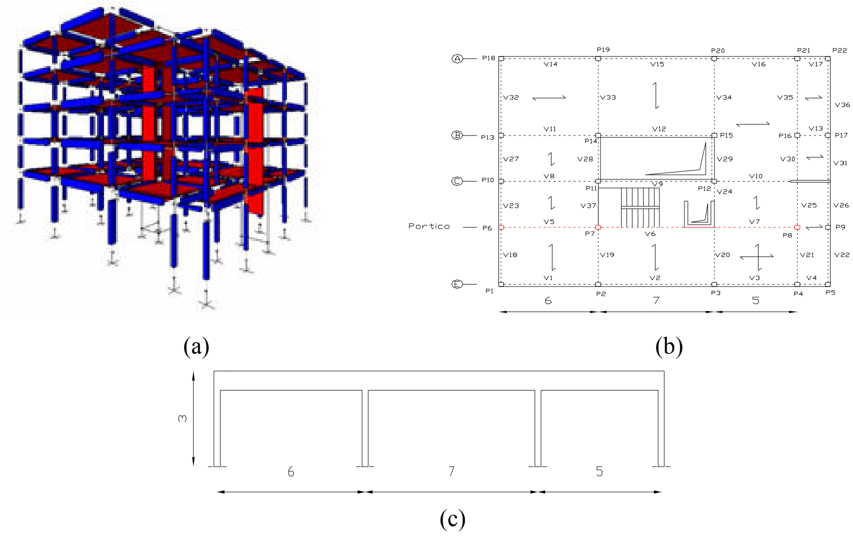

Figure 2 - structural scheme and portico of the building

The portico was constituted with tree beams of different dimensions and one type of pillar in a total of 4 pillars. The different dimensions are summarized in table 4.

Table 4 – Dimensions of reinforced concrete structural elements

Pillars	width (m)	height (m)	length (m)
P1	0,3	0,3	3
Beams			
V1	0,25	0,6	6
V2	0,25	0,6	7
V3	0,25	0,6	5

In the concrete composition per cubic meter was used 350kg of cement from the Cimpor 32.5 kind I. The aggregates used were sand rolled extracted from the river and granitic gravel with a total of 1900Kg/m^3. Was also accounted the total steel bars length used for the reinforced concrete. The pillars used ϕ 8 and ϕ20 steel bars and the beans ranged from ϕ 6, ϕ 8, ϕ 16 and ϕ 25 steel bars. The associated cost per cubic meter of concrete was 324,22€ with a total amount of reinforced concrete 3,78m^3.

Table 5 – Properties of the steel structural elements

Pillars	Type	weight (Kg/m)	length (m)
P1	HEB240	83,2	3
Beams			
V1	INP400	92,6	6
V2	INP400	92,6	7
V3	INP400	92,6	5

Concerning the equivalent steel portico, it was selected a HEB240 for the pillars and INP400 for the beams. Was determined a cost of 2€/kg with a total of 2665,2Kg of steel. Table 5 summarizes the properties of the steel used for comparison.

3 RESULTS

Analysing the figure 3, we may notice that the steel structure as greater energy consumption than the reinforced concrete structure.

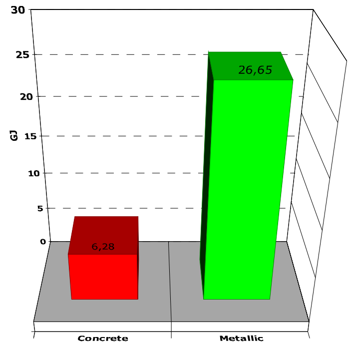

Figure 3 – Energy Consumption

The steel structure consumes about 27 GJ while the reinforced concrete structure consumes about 6 GJ, resulting in 4.5 times more energy consumption.

Table 6 – Summarized results

	Concrete	Steel
Water(m^3)	2,82	17,59
No_x(kg)	3,69	6,21
CO_2(kg)	931	4248
SO_2(kg)	5,42	3,12

The data regarding the water consumption indicates that the steel structure consumes about 6.2 times more than the reinforced concrete structure.
In the analysis made to the NO_x emissions, we can see that, once again the reinforced concrete structure does less harm to the environment; it releases approximately 2 Kg while the steel structure releases 68% more to the atmosphere.
As we examine the Carbon Dioxide emissions, the difference is quite significant. The steel structure releases 4248 Kg of CO_2 while the reinforced concrete structure releases only 931 Kg, i.e., 88% less.
Only in the SO_2 emissions reinforced concrete structure presents a larger amount, releasing 2.5 Kg, 47% more than the equivalent steel structure.

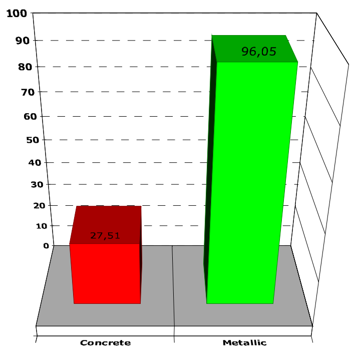

Figure 4 – Global analysis

As a result, when we carefully analyse in global terms (fig.4), it's clearly evident that the total environmental impact caused by the construction of the same portico in steel is much bigger than using reinforced concrete, causing about 3.5 more impact.

4 CONCLUSIONS

Making an analysis of the given that we can observe that the environmental impacts caused by the steel structure are vastly greater than the ones caused by the reinforced concrete structure. Consequently, the kind of structure that is friendlier to the environment is the reinforced concrete. There is only one parameter that causes more damage to the environment in the reinforced concrete structure: the SO_2 emissions. Though it makes more damage to the environment, its difference is only of 0,8Kg. We therefore conclude that globally the steel structure is less sustainable.

We consider important to add that although the steel structure is less sustainable, the steel is a resource that may reach a recyclable rate of 100%. The item wasn't considered in our study.
The developed software program can be downloaded in the Civil Eng. Materials Research Group webpage: http://www.civil.uminho.pt/web/gmc/

REFERENCES

CIMPOR – Relatório de Sustentabilidade: Actividade económica, ambiental e social. Multitema, 2003.(1)
DST – Domingos da Silva Teixeira, S.A.- Eng. Virgílio Silva (2)
Eng. Fernando Lourenço da Siderurgia Nacional (3)
Acta do Congresso Ibérico sobre Madeiras (CIMAD) (4)
www.arcelor.com (5)
BERGE, B. – *The Ecology of Building Materials*. Translated from Norwegian to English by Filip Henly, Architectural Press, Bath, 1999.(6)

Constant or variable indoor environments?
Sustainable option of adaptive thermal comfort

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ABSTRACT: In order to support the development of an adaptive thermal comfort model based on Portuguese climatic, social and psychological characteristics extensive field surveys are being carried out in occupied buildings in Portugal. This adaptive model, will consider climate, traditional ways of living in and "using" buildings, users' expectations, and major changing social, economical and psychological factors.

Field surveys are based on dedicated questionnaires and gathering information about actual climatic and indoor conditions. Behavioural aspects are being given a major attention in these surveys and will be studied under a more detailed environmental psychology approach. It will also be important to detect driving factors underlying changing trends in what regards thermal comfort expectations, attitudes and behaviours, which can either contribute to or deviate from a sustainable energy efficient everyday life practice.

This paper presents a general overview of first results obtained in two field survey campaigns.

1 INTRODUCTION

Presently there are two approaches, both controversial, that aim to estimate and to evaluate indoor environment thermal comfort conditions in buildings. The first one, an analytical approach (Fanger 1970, ISO 7730 2005), is based on experimental results obtained under controlled laboratory conditions and requires indoor control strategies, with defined narrow and stable temperature ranges usually hard to reach without the use of air conditioning systems.

The other approach, the adaptive approach, assumes that thermal comfort is a dynamic process, in which the user interacts physically and psychologically with the thermal environment. This approach assumes that the human capacity and need of adaptation, either interacting with the building and its systems, or resulting from social and cultural habits, is essential to reach a sensation of thermal comfort.

Adaptive models (Dear 1997, Humphreys 1998, Nicol 2002) assume indoor temperature variations depending of outdoor temperatures, in order to stimulate and to enable adaptive opportunities and actions. The final (desirable) results could be the users´ well-being and a reduction of energy consumption without compromising thermal comfort.

Looking at current Portuguese thermal and energy regulations (RCCTE and RSECE 2006) one can also see that indoor thermal reference conditions, like in many other countries, are defined in a static way: indoor air temperatures of 20 ºC (heating season) or 25 ºC (cooling season).

In the last years there is an increasing trend, namely in service buildings and transports (private and public), for the use (and abuse) of artificially conditioned environments. This creates a thermal "accommodation" which induces an alteration in thermal comfort "needs". Besides that, the counterpart of the use of mechanical systems is often translated by architectural options not adapted to the climate and disregarding the adaptive potential of users. In Portugal as well as in many other countries, although not always for the same reasons, service buildings are not any more built and delivered without mechanical air conditioning systems.

In the residential sector one can notice, too frequently, the adoption of inadequate building options, disregarding the prevailing external climate, the location and the orientation of the building. As a consequence this becomes a strong incentive for the acquisition, installation and unavoidable use of air conditioning devices to correct unacceptable indoor environments.

At the same time, there is an increasing offer and demand of heating, and air conditioning equipment. Several factors contribute to reinforce this tendency: increased purchasing power; social status; individual/collective attitude/tolerance towards less satisfactory thermal conditions; lower equipment costs; advertisement persuasion and financial facilities to its acquisition.

This scenario configures a progressive change in habits and expectations towards indoor thermal comfort and the means to obtain it.

Considering the high levels and continuous increase in energy consumption in buildings, along with concerns about CO2 emissions, the European Commission decided to publish the Energy Performance of Buildings Directive (nº 2002/91/CE).

The implementation and adoption of thermal comfort criteria based on adaptive models, which promote conscious attitudes and the adoption of passive measures and technologies, will contribute to the limitation of an unnecessary increase of energy consumption.

So far there is a limited number of national research studies (Guedes 2000, Nicol 2002) available in this area, and only concerning office buildings. Therefore there is an ongoing research study carried out at LNEC, which aims to develop an adaptive approach oriented to the definition of indoor thermal comfort requirements applicable to Portuguese buildings. These will consider climate, social and cultural habits, and adequate constructive solutions. Behavioural aspects are being given a major attention in this study and will deserve a more detailed environmental psychology approach. It will also be important to detect driving factors underlying changing trends in what regards thermal comfort expectations, attitudes and behaviours, which can either contribute to or deviate from a sustainable energy efficient everyday life practice.

This paper presents a general overview of first results obtained in two field survey campaigns carried out during the summer of 2006 and winter of 2007.

2 FIELD SURVEY CAMPAIGNS

2.1 *Description of buildings*

The research programme is focused on the assessment in real use conditions of indoor environment and occupant's response in service buildings. These field studies include buildings with and without air-conditioning (AC), buildings integrating passive measures/technologies (with greater adaptive possibilities) and buildings with automated control systems. Besides conventional service buildings (offices), educational buildings and elderly homes are also included. Geographical location has also been considered in order to embrace different Portuguese summer and winter climatic zones.

2.2 *Field surveys*

On the one hand, field surveys consist on the measurement of indoor environment parameters, namely air temperature (*Ta*), operative temperature (*Top*), air speed (*va*) and relative humidity (*RH*), during summer, winter and mid-season.

Measurements were performed during an hour period, at a height of 0,60 m (ISO 7726 1998) and as near as possible to the users.

Local outdoor climatic conditions (air temperature, *Text*, and relative humidity, *RHext*) where based on National Meteorological Institute data.

On the other hand, simultaneously, users have been requested to fill up a questionnaire specifically developed for this research program (Matias 2006).

The thermal index PMV, which predicts the mean value of the votes of a large group of persons exposed to the same environment (ISO 7730 2005), was calculated using the indoor parameters and the personal factors (metabolic rate and clothing insulation) estimated over the questionnaire responses.

2.3 *Questionnaires*

The global structure of the questionnaire, consisting of six groups of questions (Matias 2006), enables the acquisition of information about social and participant's characteristics (age, clothing and activity level), the identification of individual and technological adaptive opportunities, as well as the easiness and degree of satisfaction on implementing them.

In what regards psychological adaptation a series of questions were presented in order to evaluate the participant's expectations related with surrounding thermal environment. Several questions intend to identify relevant aspects of daily life experience and motivations towards the use of heating and cooling systems to control the indoor environment.

Questionnaires also intended to contribute to the characterisation and the evaluation of the influence of the factors (physical, physiologic and psychological) that determine human thermal sensation.

In that sense subjective opinion scales were defined (Matias 2006, ISO 10551 1995, ISO 7730 2005, ASHRAE 55 2004, Guedes 2000) which allow the respondents to opine about their sensations (neutrality, preference, acceptability) regarding the surrounding thermal environment.

Table 1 presents two subjective scales used in the questionnaire, respectively, thermal sensation evaluation, *TSi*, and thermal preference, *TPi*, concerning the thermal environment.

Table 1. Subjective scales

Thermal sensation (TSi)		Thermal preference (TPi)	
- 3	Cold	- 3	Much cooler
- 2	Cool	- 2	Cooler
- 1	Slightly cool	- 1	Slightly cooler
0	Neither cool nor warm	0	Like it is
+ 1	Slightly warm	+ 1	Slightly warmer
+ 2	Warm	+ 2	Warmer
+ 3	Hot	+ 3	Much warmer

3 **RESULTS**

3.1 *Sample of buildings*

During the first field campaign (summer of 2006, July-September) seven office buildings and sixteen residential homes for elderly population were surveyed. Educational buildings were not included because there were no summer classes going on.

During winter campaign (November 2006 -February 2007) new surveys have been performed in the same buildings and, additionally, six University buildings were also included.

Surveyed buildings were located in different areas of the country (Guimarães, Coimbra, Leiria, Lisbon and Faro).

Each survey was performed in places allowing the maximum number of respondents (main living rooms, classrooms, open spaces).

3.2 *Sample of participants*

Table 2 presents relevant individual characteristics, namely age, estimated metabolic rate, *M*, and clothing insulation, *Icl*, of participants inquired during the two campaigns, in the three types of surveyed buildings.

Regarding age, as expected, the differences obtained between the users of the three building types are significant, allowing an evaluation of the thermal comfort conditions for different age groups.

In each building type the analysis of the clothing insulation data in Table 2 shows small differences between both sexes. In the summer campaign the users of all buildings had similar mean values (0,59 clo), but in the winter season the mean clothing insulation of the elderly home users (1,3 clo) was significantly higher than the others participants.

Except for the elderly home data in the winter season, the observed mean values are very close to the conventional ones adopted by the ASHRAE and ISO standards (summer: 0,5 clo; winter; 1,0 clo).

Table 2. Summary of individual parameters

Building type	Gender	N	Age (years)	Metabolic rate *M*, (met)	Clothing insulation, *Icl*, (clo)	
					Summer	*Winter*
Elderly home	F	377 (75%)	82 ± 8		0,59 ± 0,1	1,3 ± 0,3
	M	128 (25%)	77 ± 9		0,60 ± 0,1	1,3 ± 0,3
	Total	*505 (100%)*	*81 ± 8*	*1,0*	*0,59 ± 0,1*	*1,3 ± 0,3*
Office	F	300 (69%)	41 ± 9		0,56 ± 0,1	1,0 ± 0,2
	M	134 (31%)	37 ± 10		0,63 ± 0,1	1,0 ± 0,2
	Total	*434 (100%)*	*40 ± 9*	*1,3*	*0,59 ± 0,1*	*1,0 ± 0,2*
Educational	F	161 (28%)	22 ± 4		—	1,1 ± 0,2
	M	315 (72%)	23 ± 5		—	1,0 ± 0,2
	Total	*476 (100%)*	*23 ± 4*	*1,2*	—	*1,1 ± 0,2*

Still regarding to the type and quantity of clothes dressed by users of the studied buildings, participant’s responses revealed that the most important criteria for the selection of the daily clothing is “*the weather condition of the day*”.

The second most influential factor for the inquired office workers and students is “*the place where they’ll stay during the day*” (25 %).

3.3 *Field surveys*

Table 3 reports the total sample of performed surveys and fulfilled questionnaires during summer (July to September 2006) and winter (November 2006 to February 2007) field campaigns.

The distribution of the studied spaces equipped with heating and air conditioning systems (AC) is also presented in the table.

Table 3. Sample building and field surveys distribution

Building type	Surveys		Questionnaires		Acclimatized spaces	
	summer	*winter*	*summer*	*winter*	*cool. and heat.*	*heating*
Elderly home (16)	34	29	242	278	12	18
Office (7)	52	52	192	252	7	13
Educational (6)	—	18	—	480	9	7
Total	*185*		*1444*		*66*	

Table 4 indicates the percentage of heating and cooling systems switched on during the thermal surveys performed in each season campaign, considering separately those rooms where the air temperature was below or above the reference thermal comfort conditions specified in the Portuguese building thermal regulation (summer: 25ºC; winter: 20 ºC).

Table 4. Heating and cooling systems use

Building type	Cooling system, (%)		Heating system, (%)	
	Ta ≤ 25 ºC	Ta > 25 ºC	Ta < 20 ºC	Ta ≥ 20 ºC
	Summer			
Elderly home	0	50	—	0
Office	85	82	—	0
	Winter			
Elderly home	0	—	69	30
Office	14	—	78	85
Educational	0	—	50	30

Content analysis of Table 4 points out the following features:

– In summer season more than 80 % of studied office rooms (with AC) had the cooling system switched on during the surveys carried out, whilst in elderly homes, 50 % of rooms were mechanically cooled but only when the temperature was above the maximum limit specified for the summer season (25 ºC).
– For the winter period a high percentage (about 80 %) of office rooms were heated no matter what the indoor temperature. For the other building types (elderly homes and universities) more than 50 % of the rooms were heated when the indoor temperatures were lower than the minimum reference value (20 º C). When the indoor temperature was above 20 ºC, the percentage of use of the heating system was low (30 %).
– Another interesting feature in winter's results is that, about 15 % of offices building were cooled even when the indoor temperature was lower than 20ºC.

Relying on the information that the participants of elderly homes can switch on the cooling system if they wish, the different pattern of use of the cooling system in elderly homes, during summer surveys, seems to indicate that their users are more tolerant (less exigent) than the respondents of offices buildings.

In the studied office buildings, for the two season campaigns, there was a significant rate of heating and cooling systems use, regardless of indoor conditions. The elevated percentage of systems use in the studied office buildings, independently of the indoor conditions, eventually denotes unnecessary energy consumption.

3.4 *Attitude towards cooling systems*

In order to evaluate the attitudes and the people's motivations towards the use of air conditioning systems (mainly cooling systems) for indoor thermal environment control, some questions have been included in the developed questionnaire (Matias 2006).

The analysis of the user's responses to these questions enables the following inferences:
– In the office and educational buildings, respectively, 22% and 11% of the respondents indicated that their home had air-conditioning (AC) installed.
– In these two types of building, the main reason for the respondents to "*don't have or don't like cooling systems (AC)*" was "*the high acquisition cost*" (19%, 26%). Whilst for the offices users the second most important reason presented was "*AC causes health problems*" (19%), for the inquired students was "*my home is comfortable*" (17%).
– The main factors indicated by the senior citizens that "*don't like cooling systems (AC)*" were "*AC cause health problems*" (40%) and "*AC creates an artificial environment*" (28%).
– In the three building types the first reason pointed out by those who "*have, like to have or enjoy AC*" was the possibility that this kind of system "*allows a constant indoor temperature*" (40 to 50%).

3.5 *General thermal environment*

3.5.1 *Thermal sensation and PMV*

Figure 1 represents the distribution of Mean Thermal Sensations (MTS) obtained in the performed surveys (left side), during summer and winter campaigns, for each building type.

Each MTS represents the mean value of all individual votes (TSi), using the thermal sensation scale (Table 1), in every survey carried out.

The right side of Figure 1 shows the distribution of the Predicted Mean Votes (PMV), calculated for all surveys performed in the two seasons.

The following conclusions can be drawn from Figure 1 analysis:
– During summer campaign greater MTS percentages, regardless the type of buildings, fall under categories 0, "*neither cool nor warm*" (offices: 47%; homes: 71%), and 1, "*slightly warm*" (35% and 27%), of the thermal sensation scale (Table 1);
– PMV values show a similar relative percentage distribution (greater % falling under 0 and 1); nevertheless the fact that PMV percentage values falling under 0 are lower than corresponding MTS percentage values, and those falling under 1 are greater, indicates that the PMV index predicts slightly warmer environments than user's expressed perception;

– MTS values obtained during winter campaign in offices and classrooms indicate, as above, greater percentages under 0 (ofices: 52%; homes: 44%) and 1 (40% e 50%), values in both categories are not very different; on the contrary values obtained in elderly homes show that 93% of mean thermal sensations fall under *neutral* category (0, "*neither cool nor warm"*);
– During the winter campaign 70% of PMV values fall under category 0 *("neutral")*, regardless the building type, what, except for the case of elderly homes, does not match user's expressed thermal sensation (MTS); contrary to summer results, PMV predicts slightly cooler environments than expressed by users.

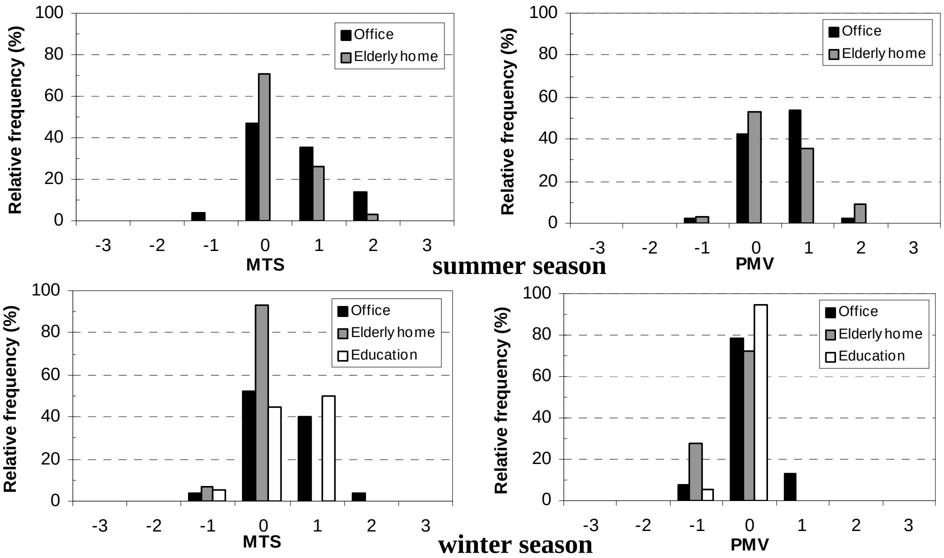

Figure 1. Mean thermal sensation (MST) and predicted mean votes (PMV)

These discrepancies observed between estimated (PMV) and expressed (MTS) thermal sensations, already pointed out in several other research studies (mainly referring to naturally ventilated buildings), justify the interest in developing an adaptive thermal comfort approach in the specific Portuguese context.

3.5.2 *Thermal sensation and thermal preference*

Tables 6 (summer campaign) and 7 (winter campaign) present cross-relations between users´ thermal *sensation* (TSi) and thermal *preference* (TPi) votes, according to subjective scales defined in Table 1.

In both seasons (Tables 6 and 7) when TSi = 0 ("*neither cool nor warm")* users´ main preference (summer: 79 %; winter: 76 %) is to keep the thermal environment "*like it is*" (TPi = 0). Nevertheless 20% of the expressed votes indicated that users would rather prefer a "*slightly cooler*" environment (TPi = –1) in summer, and a "*slightly warmer*" in winter (TPi = 1).

This fact allows to assume that external climatic conditions may influence thermal preference, once that, although being in a neutral situation (TSi = 0), in summer time users would prefer to feel slightly cold and in winter slightly warm.

When analysing results (Table 6) regarding respondents that would prefer to keep the thermal environment "*like it is*" (TPi = 0), in summer campaign a large majority of responses (89%) classifies it as "*neither cool nor warm*" (TSi = 0); in winter campaign (Table 7) although 72% of votes correspond to TSi = 0, 21% consider that the thermal environment is "*slightly warm*" (TSi = 1).

This result seems to indicate that users would rather have a neutral environment (Tsi = 0) in summer, while in winter the option lies between a neutral and a slightly warm environment (TSi=0 or 1).

Confirming this winter trend (Table 7), 52% of those respondents who voted "*slightly warm*" (TSi=1) expressed the preference to keep the environment "*like it is*" (TPi=0).

Values presented in Tables 6 and 7 were calculated based on the whole sample results (all inquires), respectively obtained during summer and winter campaigns. Nevertheless general conclusions of the analysis performed and presented in 3.5.2 are valid in what regards TSi e TPi, independent of type of building (offices, elderly homes and universities) and use of air-conditioning (AC).

Table 6. Cross-Tabulation of thermal sensation (TSi) vs. preference thermal (TPi) votes in summer season

			TPi				
			-3	-2	-1	0	+1
TSi	-1	% TSi	3,1%		3,1%	37,5%	56,3%
		% TPi	25,0%		0,7%	5,1%	78,3%
	0	% TSi		0,4%	19,0%	78,7%	1,9%
		% TPi		4,2%	33,6%	88,5%	21,7%
	+1	% TSi		7,3%	77,1%	15,6%	
		% TPi		29,2%	49,7%	6,4%	
	+2	% TSi	3,1%	31,3%	65,6%		
		% TPi	25,0%	41,7%	14,1%		
	+3	% TSi	18,2%	54,5%	27,3%		
		% TPi	50,0%	25,0%	2,0%		

Table 7. Cross-Tabulation of thermal sensation (TSi) vs. preference thermal (TPi) votes in winter season

			TPi				
			-2	-1	0	+1	+2
TSi	-3	% TSi					100,0%
		% TPi					4,5%
	-2	% TSi				40,0%	60,0%
		% TPi				1,7%	27,3%
	-1	% TSi			4,0%	87,0%	9,0%
		% TPi			0,7%	36,9%	40,9%
	0	% TSi		2,8%	75,9%	21,0%	0,3%
		% TPi		11,3%	72,4%	51,3%	9,1%
	+1	% TSi	0,4%	39,3%	51,6%	7,4%	1,2%
		% TPi	16,7%	68,1%	20,8%	7,6%	13,6%
	+2	% TSi	4,2%	38,0%	47,9%	8,5%	1,4%
		% TPi	50,0%	19,1%	5,6%	2,5%	4,5%

3.5.3 *Thermal sensation and indoor temperature*

Figure 2 shows the percentage distribution of Mean Thermal Sensation (MTS) obtained in summer and winter campaigns, in office and elderly home buildings.

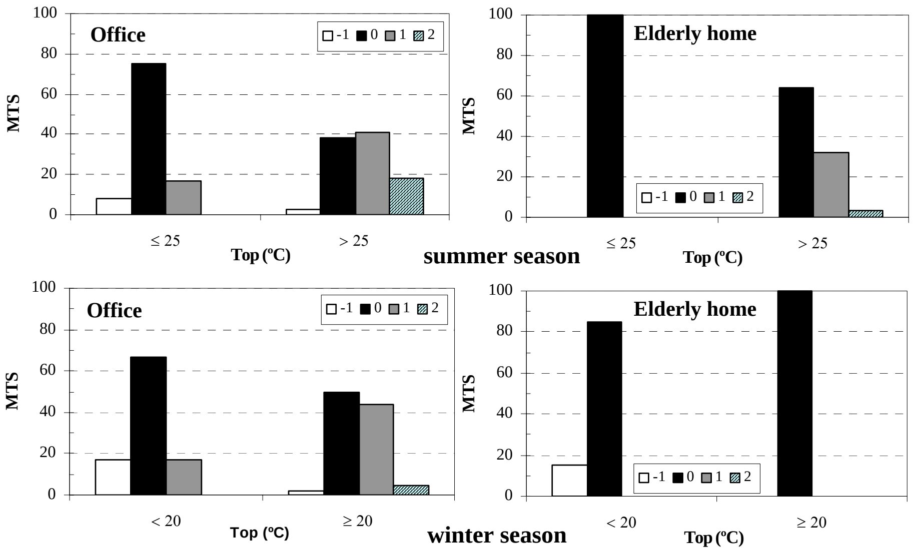

Figure 2. Percentage distribution of MTS below or above the reference temperature (25ºC and 20ºC)

Presented MTS values correspond to two ranges of indoor operative temperature (Top): below or above the reference thermal comfort conditions specified in the Portuguese building thermal regulation (summer: 25ºC; winter: 20 ºC).

A preliminary conclusion that can be taken from Figure 2 is that, beyond the reference limits defined in the national regulations, still a significant percentage of mean thermal sensation (MTS) ranged between –1 (*"slightly cool")* and 1 (*"slightly warm")*.

It should be noted that measured indoor operative temperatures ranged between 16 and 25 ºC in winter, and 22 and 31 ºC in summer.

4 CONCLUSIONS

A general overview and first results of two field campaigns carried out, under an ongoing research study about indoor thermal comfort, have been presented and analysed.

Some relevant objective and subjective aspects are emerging from the present analysis. The measurements performed and the questionnaire that has been elaborated and applied on the field surveys is providing useful information about such aspects.

Detected attitudes towards the use of air conditioning systems, thermal sensations and preferences expressed by the respondents indicate the existence of deviations from the results obtained by the conventional analytical method, justifying the proceeding of research work oriented to an adaptive approach.

A more detailed analysis and new surveys are required in order to support the development of an adaptive approach oriented to the definition of indoor thermal comfort requirements applicable to Portuguese buildings.

REFERENCES

/P/ - Leis, decretos, etc. 2006. RCCTE - Regulamento das Características de Comportamento Térmico dos Edifícios (Decreto-Lei n.º 80/2006, de 4 de Abril). DR nº 67, I SÉRIE-A, p. 2468 a 2513.

/P/ - Leis, decretos, etc. 2006. RSECE - Regulamento dos Sistemas Energéticos de Climatização em Edifícios (Decreto-Lei n.º 79/2006, de 4 de Abril). DR nº 67, I SÉRIE-A, pp. 2416 a 2468.

ASHRAE 55 2004. Thermal environmental conditions for human occupancy. Atlanta, USA.

Baker, N. and Standeven, M. 1996. Thermal comfort for free-running buildings. *Energy and Buildings* 23: 175-182.

Dear, R. & Brager, G. 1997. Developing an adaptive model of thermal comfort and preference, Final Report on Project RP-884, Maquarie University, Sydney: p. 296.

Fanger, P. 1970. *Thermal comfort. Analysis and applications in environmental engineering*. Denmark: McGraw-Hill.

Guedes, M. 2000. Thermal Comfort and Passive Cooling Design in Southern European Office Buildings. The Martin Centre, University of Cambridge (PhD Thesis).

Humphreys, M. & Nicol, F. 1998. Understanding the Adaptive Approach to Thermal Comfort. *ASHRAE Transactions* 101 (1): 991-1004.

ISO 7726 1998. Ergonomics of the thermal environment – Instruments for measuring physical quantities. Genève, Switzerland.

ISO 7730 2005. Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Genève, Switzerland.

ISO 10551 1995. Ergonomics of the thermal environment – Assessment of the influence of the thermal environment using subjective scales. Genève, Switzerland.

Matias, L., Santos, C. & Guedes, M. 2006. Condições de conforto térmico em edifícios em Portugal. Modelo adaptativo. "*Encontro Nacional Sobre Qualidade e Inovação na Construção – QIC2006"; Proc. nat. symp, Lisbon, 21-24 November 2006*: 355-365.

Nicol. F. & Humphreys, M. 2002. Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings* 34: 563-572.

Developing a method to characterize indoor environmental parameters in naturally ventilated classrooms

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ABSTRACT: Until recently, there has been little investigation concerning the poor indoor air quality (IAQ) in classrooms. Despite the evidence that the educational building systems in many of the UK institutions have significant defects that may degrade IAQ, systematic assessments of IAQ measurements has been rarely undertaken. When undertaking IAQ measurement, there is a difficult task of representing and characterizing the environment parameters. Although technologies exist to measure these parameters, direct measurements especially in a naturally ventilated spaces are often difficult. This paper presents a methodology for developing a method to characterize indoor environment flow parameters as well as the Carbon Dioxide (CO_2) concentrations. Thus, CO_2 concentration level can be influenced by the differences in the selection of sampling points and heights. However, because this research focuses on natural ventilation in classrooms, air exchange is provided mainly by air infiltration. It is hoped that the methodology developed and evaluated in this research can effectively simplify the process of estimating the parameters for a systematic assessment of IAQ measurements in a naturally ventilated classrooms.

Keywords: Carbon Dioxide, Indoor air quality, Infiltration, Natural Ventilation and Parameters.

1 INTRODUCTION

The connection between the use of a building either as a workplace or as a dwelling and the appearance, in certain cases, of discomfort and symptoms that may be the very definition of an illness is a fact that can no longer be disputed. The main culprit is contamination of various kinds within the building, and this contamination is usually referred to as "poor quality of indoor air". The adverse effects due to poor air quality in closed spaces affect a considerable number of people since more people spend up to 90% of their time indoors (Klepeis, WC et al. 2001; Wu, RJ et al. 2005; Hui, L.T.Wong et al. 2006) For example, Robinson and Nelson (1995) reported that, on average, US individuals spent 88% of their day inside buildings, and 7% in a vehicle. Only 5% of participants' time was actually spent outside. Public concern about adverse effects of indoor air has increased in recent decades, starting from the 1970's in which residence and commercial building users reported health problems associated with their buildings (Kreiss 1989). Eye, upper respiratory tract irritation, fatigue headache and breathing difficulties are among the common reported complaints in that point of time. While current research on indoor air quality mainly focuses on residences and offices, few studies are concerned with the indoor environment of school buildings, however recently, an increase reporting on this issue has been found particularly in commercial buildings and schools.

Children in particular, spend more time in school than any other indoor environment apart from home. Taking this into account, it becomes evident that the study of the indoor air quality and the CO_2 concentration levels in a classroom should be a priority. The more reason for this is that children have greater susceptibility to some environmental pollutants compared to adults. They breathe higher volumes of air relative to their body weights and their tissues and organs are actively growing (Melikov, U.Kruger et al. 1997; Faustman, S.M et al. 2000). The factors affecting indoor air quality in schools are generally the same as for other buildings, but some are particularly relevant. There is considerable variation in the design of school buildings throughout the UK, according to their location, size and age. The materials used in their construction and furnishings vary, as do the rate and type of ventilation. These variations mean that the relative importance of factors affecting indoor air quality varies from school to school; nonetheless it is useful to identify some factors. It is seen that an adverse environmental effects on the learning and performance of students in schools could have both immediate and lifelong consequences, for the students as well as for the society. However in this research as a preliminary study, the focus will be in the higher educational classrooms.

Many researches have carried out questionnaires on occupants' perception of IAQ in a structured and validated manner. However this information alone would not be sufficient to identify either the root cause of any dissatisfaction or exposure to pollutants that are not perceived prior to causing harm. Therefore over the last few years several schools studies have been made (Lazzerini, D et al. 1991a; Lazzerini, D et al. 1991a; Seppanen, Fisk et al. 1999; M.Kolokotroni, Ge et al. 2002; Fromme, T et al. 2005; Wu, RJ et al. 2005). It is shown that good ventilation controls and air quality influences the well being of school occupants especially the school children. Therefore many similar studies have been made throughout the world.

In effect, studies examining children's exposure have shown that the largest percentage of exposure was received at home and in the school (Wu, RJ et al. 2005) . Several studies have examined indoor air quality in schools and have found significantly high CO_2 concentration levels.

2 PROBLEM STATEMENT

It is well documented that the IAQ in schools is both inadequate and frequently much worst than in office buildings. The most common defects in schools include insufficient outside air supplied to occupied spaces especially in schools with natural ventilation systems.

Most schools are not air conditioned, relying instead on natural ventilation, which aids the dispersion of pollutants that originate within the building, at least in warmer weather when windows are open. In cooler weather, when windows are likely to be closed most of the time, ventilation rates in schools that rely on natural means is likely to be lower. Where there are significant outdoor sources of air pollutants, such as in schools located near major roads, a higher ventilation rates are likely to diminish air quality by allowing a greater influx of airborne pollutants from outdoors.

If the air in a room is pollutant, more soot and ozone will be inhaled by the students. The distribution of air within rooms and among rooms is inextricably linked to indoor air quality. Airflow within a room affects the emission rate at which contaminants emit into the air from sources within the room. These airborne contaminants are transported within the room and among rooms primarily by the room airflow. The amount of air introduced into the room, the ventilation rates, the quality of that air, and the way the air is diffused, into the room are important factors determining the outcome conditions. A lack of ventilation air can lead to an inadequate levels of air required for respiration and an adverse impact on IAQ. In particular, internally generated pollutants can build up. Although there are many of common pollutant in the air, CO_2 concentration and odour intensity were found to be the dominant pollutants when considering outdoor air supply rates (Clements-Croome, Awbi et al. 2006). Studies in UK schools have indicated levels of CO_2 in excess of 4000 ppm and ventilation rates of less 0.5 l/s per person(Coley and Beisteiner 2003) . Zhang (2007) affirmed that classrooms environments with a mechanical ventilation system reduce carbon dioxide levels and relative humidity. It also increases the air exchange rate meaning an increased rate of supply of fresh air for the rooms' occupants. Figure 1 shows that the CO_2 concentration level in one of the measured classrooms has been reduced significantly by using the additional mechanical ventilation system. Under normal conditions relying solely on natural ventilation without any openings, the CO_2 concentration increases, when the pupils enter the classroom as shown by the peaks in the graph.

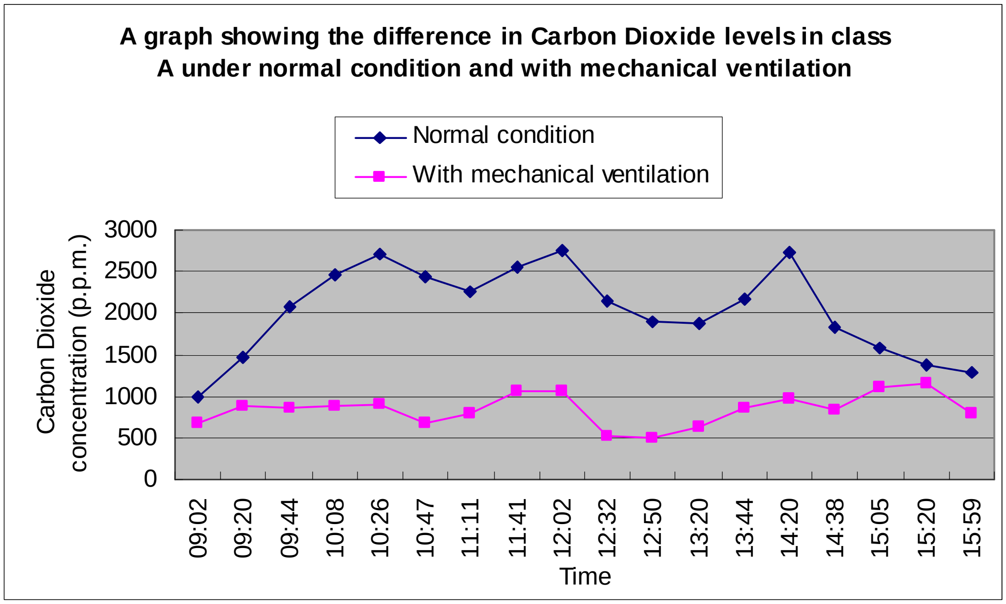

Figure 1: CO_2 concentration level in a classroom under different conditions.

Another study carried out in Poland shows that throughout the whole period in which the classroom was used, CO_2 concentration exceeded 1000 ppm (Sowa 2002). These results show that there is an urged requirement to research more on the CO_2 concentration and how it is being dispersed and distributed in the air. Better data are needed on the statistical distribution of CO_2 concentrations. Such information would provide a starting point for optimizing indoor air quality in these buildings, leading to improved health and children learning performance.

Increasing the fresh air ventilation rate is often an effective way to improve indoor air quality, however it is not easy to mix the air in a room by just having a natural ventilation system. Thus air distribution within rooms and among rooms is important in attaining desirable indoor air quality. With growing concern in the past decade over complaints attributed to IAQ, environmental parameters have been suggested and adopted for IAQ assessment of a space by many researchers. However, until today, although research in IAQ has established a lot of new information, it has still not been possible to agree on one international standard. The most internationally used standard for IAQ and ventilation is ASHRAE Standard 62.1(2004). Countries including the UK, Canada, Japan, Korea, Singapore, Sweden and the USA have conducted IAQ studies for a long time that aim to set standards and guidelines (Humfrey, Shuker et al. 1996; Hoskins 2003). As a number of studies showed that measurements and the analysis of indoor CO_2 concentration would be useful for understanding IAQ and ventilation the choice of CO_2 for demonstrating the variations of the IAQ measurements could be a representative pollutant for general IAQ monitoring and measurements guidelines (Committee of European Normalization; Hui, Wong et al. 2006; Mui, L.T.Wong et al. 2006; Mui, L.T.Wong et al. 2006). Recently, a study in an office building was investigated and concluded that when the number of sampling points required for IAQ measurement was reduced to 50%, the probability of obtaining the sample-spatial average concentration at the same confidence level would be decreased by 10% (Hui, L.T.Wong et al. 2006).

3 PREVIOUS STUDIES

The indoor carbon dioxide concentration depends on the number of occupants (number of pupils in classroom), ventilation rate and room volume. CO_2 concentrations are often used for specifying outdoor air supply rates per occupant. Indoor CO_2 concentrations above about 1000 ppm are generally regarded as indicative of ventilation rates that are unacceptable with respect to body odours. Many researches were carried out looking into measurement and monitoring the CO_2 concentration levels in naturally ventilated classrooms. However, it is seen that monitoring were made in different ways accordingly to the researcher's choice of sampling.

One of the monitoring researches done was in a number of naturally ventilated, state-owned primary schools that measure the CO_2 levels. Internal measurements of CO_2 were made every five minutes for 8 hrs. The equipment was wall mounted (or placed on a bookshelf) at a height of about 1.8m. The result of the experiments show CO_2 concentration which are far beyond the guideline value of 1000ppm (the average concentration during the occupied period was 1957 ppm) and that in some classrooms the level exceeded the range of the detector (4000 ppm). (Coley and Beisteiner 2003).

Another research carried out in Michigan has attempted to place samplers in representative locations that were secure from tampering, at least 0.6 m above the floor and below the ceiling and at least 0.5 m away from bookshelves and other potentially stagnant areas. Results also show that CO_2 concentration often exceeded 1000 ppm and sometimes 3000 ppm.

As far as possible, sensible locations was chosen for the equipment in those locations near doors and windows or over heaters were avoided (Godwin and Batterman 2007).

In the city of Athens, 10 secondary public schools were selected to study the pollution level. All measurements were performed in occupied classrooms during lesson hours (8.15 – 14.15). Sampling equipment was placed at 1.5 m above the ground level at indoor locations in the middle of the classrooms. The concentrations of indoor CO_2 was found to exceed the ASHRAE comfort value due to crowded classrooms and inadequate ventilation (Grimsrud, B.Bridges et al. 2006). The same height of measurement set-up was used in another research carried out in schools located in Minnesota, US which is at approximately the level of human breathing zone (Valavanidis and Vatista 2006).

On the whole it was found that without specifying the height and specific representative sampling location, most of researchers have the same opinion in placing the measurement set-up at a central location in the classroom (Dijken, Bronswijk et al. 2006).

Consequently, multiple locations should be used to characterize IAQ parameters in classrooms. While care was taken in monitoring site placement, some measurement may not be representative, e.g., the highest CO_2 concentrations might have resulted from persons breathing on the instruments.

4 RESEARCH AIM

In the past, anxiety over criticism attributed to IAQ lead to environmental parameters being recommended and adopted for IAQ assessment and measurements. In many National and International standards and protocols, the measurements of key parameters to undertake IAQ assessment were listed.

By taking the confirmed assessment uncertainties into account, the new assessment of CO_2 measurements would be seen to be a useful tool for policymakers, building owners and professional to identify the IAQ problems in schools and to make decisions on resources for efficient mitigation actions as well as IAQ improvements. However the current research does not cover the study of occupant's perceptions of IAQ and the recording and assessments of complaints about IAQ. The focus of this research is on the measurements methods which will be in the context of a particular design and purpose for an investigation and monitoring guidelines of IAQ assessment. The purpose would be to determine whether IAQ parameters fall within acceptable limits. Issues such as technical difficulties, interpretations of data, numbers of sampling methods with various sampling points and heights will all be explored. The sampling points and locations in a natural ventilated space would contribute to the method of interpreting the results due to spatial variations in CO_2 concentrations.

The objectives of this research are:

- To examine the national and international standards and guidelines on CO_2 measurements and protocols in buildings.
- To investigate the variations of CO_2 concentration level through space as well as with time in classrooms.
- To developed a CO_2 measurement methods and guidelines for a better understanding of indoor air quality monitoring with particular application to classrooms and high occupancy density buildings.

5. RESEACH FRAMEWORK

This research consist of various studies, the first is to evaluate the UK's and other countries' IAQ measurements protocol and guidelines by means of desk study and expert evaluation of the guidelines in daily practice. Then, a worldwide literature study will be carried out to gather the newest scientific insights and examples of foreign guidelines. The exhalation rate is then determined and parallel to that, suitable sampling locations will be identified. With extensive field testing in preparation, the experimental work is also evaluated using computer simulations. The measurement protocols and guideline will be finalized based on these field studies and simulations.

5.1 *Preliminary Studies*

A number of classrooms will be used to determine the variation of CO_2 concentration in the space during the measurement periods. All measurements are taken when the room is occupied. As mentioned (Melikov, U.Kruger et al. 1997) the occupied zone in classrooms can be difficult to define, as many different kinds of activity can take place within the space. Therefore CO_2 concentration levels are determined in accordance with the activity throughout the whole period in order to identify the variations in time. On the other hand, measurements are taken in a small naturally ventilated room to study the exhalation rate of CO_2 and determine its distribution in the air. Vertical and horizontal CO_2 distributions are important characteristics in monitoring the classroom. As stated earlier, different researchers have different preferences on the sampling points selections. Therefore to validate and investigate the variations in CO_2 concentration, measurement is performed generally at four different heights above floor level: 0.6m, 1.5m, 1.8m and 0.6 below the ceiling. These heights were selected on the basis of previous studies. On the other hand, a supplement of 4 different sampling points will be placed at the front, right, left and in the middle of the classrooms. Furthermore, the locations for the sampling equipment are chosen to be unobtrusive; at least 50 cm from any wall, and located at the surrounding of a seated person with multiple height measurements. Care is taken to assure that sampling would not be influenced by fans or ventilation systems. At each location, it is recommended that sampling is to be performed in duplicate over a 3–4 h period and measurements will be conduced over two consecutive days. For this study, the measurement will be placed in a number of classrooms in the University of Reading.

6 CONCLUSION

Assessment methods that rely on monitoring some representative pollutants have been proposed at different spatial locations in the room. However, specific measuring protocols of CO_2 concentration that apply to naturally ventilated schools or educational institution buildings have yet to be developed. Sampling should be conducted on the basis of a monitoring plan and a clear strategy. This is mainly because the CO_2 being dispersed and distributed in the air is not constant at all times. In this study, indoor CO_2 concentration is selected as an indicator of the IAQ to investigate the measurement methods and probable errors in different sampling preferences with regards to the sampling points' locations and distribution. The rationale for this selection will hopefully lead to developing guidelines for practical evaluations of IAQ measurements.

7. FUTURE RECOMMENDATIONS

Although this is only a preliminary research there will be more to cover in future to develop a CO_2 measurement methods and guidelines for a better understanding of IAQ monitoring with particular application to classrooms and high occupancy density buildings. Future research framework would cover the following.

7.1 *Building measurement for ventilation assessment*

To avoid the influence of the surroundings (streets, other building etc.) the building selected should be far away from crowded and noisy city centre but in an open area in suburbs. Primary schools have been chosen for study in this thesis because the high occupancy density has the effect of magnifying the variability of environmental conditions. Classrooms are selected randomly from each school. The CO_2 are monitored in real time and are used to estimate the effective ventilation rate as a function of time and occupancy. An estimation of the air change rate should be obtained and simultaneously measurements of both indoor and outdoor CO_2 levels are required at regular intervals over a time period of concern. Additional data requirements include the volume of the rooms and an accurate time-based count of the people present in the tested area.

7.2 *Computer Simulation*

CFD simulations will be carried out to map the distribution of CO_2 in the room which is subjected to CO_2 measurement. The CO_2 species will be treated as passive contaminant and then as active contaminant with a different density to the air to provide a comparison.
In CFD simulations, preparing input information and analyzing the outputs are the most crucial parts in addition to the model itself. To provide enhanced functions, VORTEX© CFD code will be used as well as other commercial codes. CFD models are suited for giving detailed results but are very sensitive to boundary conditions, like the building geometry, and require a high level of comuting power. However, CFD techniques are more and more applied to an entire building or even to a complete built up area. It is a challenge for current CFD models to simulate natural ventilation. Given the increasing interest in natural ventilation, attention should be directed towards modeling and especially to the specification of the boundary conditions

REFERENCES

Clements-Croome, D. J., H. B. Awbi, et al. (2006). "Ventilation Rates in Schools." Building and Environment(article in press corrected proof): 1-6.

Coley, D. A. and A. Beisteiner (2003). "Cabon Dioxide Levels and Ventilation Rates in Schools." International Journal of Ventilation **1**(1): 45-52.

Committee of European Normalization, C. Ventilation for buildings: design criteria for the indoor environment. L. C. o. t. E. C. Brussels, Directorate General for Sience, Research and Development Joint Research Centre-Environment Institute;1998. **CR1752**.

Dijken, F. V., J. E. M. H. V. Bronswijk, et al. (2006). "Indoor environment and pupils' health in primary schools." Building Research & Information **34** (5): 437-446.

Faustman, E. M., S. S.M, et al. (2000). "Mechanisms underlying children's susceptibility to environment toxicants." Environmental Health Perpectives **108**: 13-21.

Fromme, H., L. T, et al. (2005). "Elemental Carbon and respirable matter in the indoor air of apartments and nursery schools and ambient air in Berlin (Germany)." Indoor Air **15**: 335-341.

Godwin, C. and S. Batterman (2007). "Indoor air quality in Michigan schools." Indoor Air **17**: 109-121.

Grimsrud, D., B.Bridges, et al. (2006). "Continuous measurements of air quality parameters in schools." Building Research & Information **34**(5): 447-458.

Hoskins, J. A. (2003). "Health effects due to indoor air pollution." Indoor and Built Environment **12**: 427-433.

Hui, P. S., L.T.Wong, et al. (2006). "Feasibility study of an express assessment protocol for the indoor air quality of air-conditioned offices." Indoor and Built Environment **15**(4): 373-378.

Hui, P. S., L. T. Wong, et al. (2006). "Evaluation of professional choice of sampling locations for indoor air quality assessment." Building and Environment(article in press): 1-8.

Humfrey, C., L. Shuker, et al. (1996). IEH Assessment on Indoor Air Quality in the Home. M. R. Council, Institute for Environmental and Health.

Klepeis, N., N. WC, et al. (2001). "The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants " Journal of Exposure Analysis and Environmental Epidemiology **11**: 231-252.

Kreiss, K. (1989). "The epidemiology of building related complaints and illness." Journal of Occupational and Environmental Medicine **4**: 575-592.

Lazzerini, R., C. D, et al. (1991a). ANNEX XV-Energy Efficiency in schools. Part two, EIA-International Energy Efficiency.

Lazzerini, R., C. D, et al. (1991a). ANNEX XV-Energy Efficiency in schools. Part one, IEA-International Energy Agency.

M.Kolokotroni, Y. T. Ge, et al. (2002). "Monitoring and modelling indoor air qualty and ventilation in classrooms within a purpose-designed naturally ventilated school." Indoor and Built Environment **11**: 316-326.

Melikov, A. K., U.Kruger, et al. (1997). "Air Temperature Flactuations in Rooms." Building and Environment **32**(2): 101-114.

Mui, K. W., L.T.Wong, et al. (2006). "A new sampling approach for assessing indoor air quality." Indoor and Built Environment **15**(2): 165-172.

Mui, K. W., L.T.Wong, et al. (2006). "Evaluation on sampling point densities for assessing indoor air quality." Building and Environment **41**: 1515-1521.

Nielsen, P. V. (1995). Airlow in a world exposition pavilion studied by scale-model experiments and computatioal fluid dynamics. Vol 101/2, ASHRAE Transaction.

Seppanen, O. A., W. J. Fisk, et al. (1999). "Association of ventilation rates and Co2 Concentrations with health and other responses in commercial and institutional buildings." Indoor Air **9**: 226-252.

Sowa, J. (2002). Air Quality and Ventilation Rates in School in Poland - Requirements, Reality and Possible Improvements. Indoor Air 2002, Monterey,California.

Valavanidis, A. and M. Vatista (2006). "Indoor air quality measurements in the Chemistry department building of the University of Athens." Indoor and Built Environment **15**(6): 595-605.

Wu, C. F., D. RJ, et al. (2005). "Exposure assessment and modelling of particulate matter for asthmatic children using personal nephelometers." Journal of Atmospheric Environment **39**: 3457-3467.

Zhang, G. H. (2007). The Impact of Ventilation Rate on Primary School Pupil's Peformance. Construction Management & Engineering. Reading, University of Reading. **Degree in Construction Management & Quantity Surveying**.

Towards an integrated decision process of sustainable urban projects

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ABSTRACT: This works aims at defining a multi criteria decision making method for the evaluation of sustainable urban projects. This integrated approach starts by investigating and describing the system of sustainable oriented goals of each decision makers working on an urban project. By modeling the final objectives in the form of tree structure, one obtains the reference frame which will make it possible to evaluate a sustainable performance for each decision maker. Then we will use a specific algebra to merge the tree structure of each actor of the decision process into a generic tree structure. Next we build criteria (indicators of sustainability) to represent each objective. Each criterion is provided with standard values to define various distances to the objective. Lastly, by incorporating the criteria on any level of the tree structure, and by using the Electre-Tri aggregation method, it is proposed an evaluation of each objective. A computer tool baptized Impact is embedding these various techniques.

1. CONTEXT

The urban development is characterized by wide mutations: extension and dilution of cities, spatial segregation, new mobility, acceleration of time, acceleration and multiplication of environmental impacts (space, resources or energy, noise, landscape…), strong interweaving of problems and solutions.

The urban decision simultaneously is renewed by the eruption of sustainable development and notably the strong presence of two of its components: environment and governance.

New environmental themes such as the impact on the health, the greenhouse effect and the urban sprawl, play nowadays a basic role. The issues are widenning. The responses are more complex, from the modification of the urban structure to progress of the technology. One tries to compare "the non-comparable" while implementing non commensurable criteria or which can get into conflict. Governance calls for a multi actors' decision, where the public, as eco-citizen plays a central role. The decision-maker is no more an identified person but an informal group, with divergences of opinions between actors. One passes from an optimization strategy to a strategy of "reasonable compromise" between non homogenous constraints: a new culture of thinking. These two aspects are reaching a strong request by the decision-makers for an evaluation tool or for assistance to the decision with both, usage simplicity and scientific relevance. This request of a simplified diagnosis tool requires a compromise between a necessarily simplified modeling of the reality allowing the tool to stay operational, and a relative exhaustiveness of the various and numerous relevant dimensions. At last, the decision becomes a multi scale process, both for space and time. The geographic scale of the phenomena can cover very vast territories. The temporal scale can vary from short to long term, the "trans-generational scale".

In this context, a family of tools is considered as a reference, the systems of environmental indicators. Our work is part of this movement. This approach is marked by a strong multidimensional and applied character: the methodology can be extrapolated to various thematic fields aiming at the construction of wide systems of indicators (UNO, 1992).

The most important limit of the current systems seems to be linked to their construction method: these systems are based on a bottom-up approach, from the available data. Their feasibility is therefore important, but on the other hand, not any aggregation is available. Our work is different from these referential approaches which are not able for example to compare environmental impacts of two projects on a given territory. It is essential for us to move off from this classical exercise of collection/ concatenation of varied indicators, and to propose real assistance tools for the environmental evaluation of urban projects, within an innovating morphologic and structural framework for the elaboration and the implementation of these systems of indicators (Maurin, 2004).

2. METHODOLOGY

In our work, following the example of the *SagaCités* project (Adolphe, 2002), we have combined a top-down descending and bottom-up climbing approaches. In a first stage, we privilege the descending approach, by using the decision-makers'goals aiming at the structuring of the system of indicators, and by using a formal reconstruction of the systems for the selection of the indicators. We define our indicators, not from the available data, but from the objectives of the decision-makers, while using an original approach, the approach by values, developed by Keeney (Keeney,1992) allowing to define the basic objectives that a group of decision-makers is aimaing at. We combine this descending approach with an bottom-up approach, by taking into account, not only the feasibility of the system, but again the results of a consultation process driven with various actors of the domain. The interest of the system is in fact based on the definition of a series of definite criteria (quality and packaging of the data, scientific relevance…), but also informational (potential of communication…). At last, we take into account the preferences of the decision-makers while using a multicriteria assistance method, the Electre-tri method.

The proceeding is therefore as follows: 1) structuring of the preoccupations of the decision-makers, 2) structuring and selection of the indicators, 3) local aggregation, 4) suggestion of a system of indicators in a evaluation aided tool.

The first step of this proceeding aims at structuring the preoccupations of the decision-makers. Our goal is not here to put forward the one or the better decisions to be taken, in comparison with the preferences of the decision-maker, but to evaluate an environmental position in comparison with the objectives of the decision-maker. To do so, we have used the approach by values of Keeney that we hybridize by declining the final objectives reflecting the system of values of the decision-makers. The hierarchies of objectives are thus obtained by investigating a panel of thematic experts. Next, we merge the structures of objectives to obtain a generic structure of objectives (Rousval,2005).

The following step aims at the construction of the indicators. It combines two concurrent approaches: the structuring of the system, and the selection of the indicators. The structuring of the system is based on the association of an indicator to one or several final objectives in the hierarchy of previously defined objectives. The selection of the indicators and of the resultant system is based on a body of formal and informational criteria such as the appropriateness to the objective, the scientific coherence, the space end time, etc…

At last, we aggregate the system of indicators, within a theme, by combining in a synthetic indicator, or by geographic or temporal aggregation, or between various themes. For this last stage, a partial aggregation method is used, the Electre-Tri method.

3. STRUCTURATION OF THE DECISION MAKERS ‘PREOCCUPATIONS

The evaluation is a process that aims at quantifying and/or qualifying a system, thanks to all necessary information for building criteria allowing to reach the objectives concerning this system and pertinent in the framework of a wider but previously identified activity (Rousval, 2005).

Our work is based on the paradigm of the evaluation aid rather than the one of the assistance to the decision. In fact the decision aims at the comparison between projects, while the evaluation aims a degree of proximity to the objectives. We look therefore to put forward the better decisions to compare with the preferences of the decision-maker or to evaluate an environmental position in comparison with the objectives of the decision-maker. This way to envision the evaluation takes place in the "evaluation management" model of thought. It is an rationalization approach by the objectives that takes into account the “final-means” distinction to structure the objectives. This innovating approach has been developed around the PhD’s thesis of Benjamin Rousval (Rousval, 2005).

The "Value Focused thinking" or approaches by values, proposed by Keeney does not focus the action on the possible decisions, but on the basic objectives reflecting the values of the decision-makers. The evaluation consists in an assessment, with criteria, of the degree of proximity of projects in comparison with a norm (Abernot, 1996). When the object represents an essential reason for the decision-maker concerning the decision-making position, it is a final objective, as opposed to the means objective, that does not represent an end by itself for the decision-maker, but a means to reach a final objective. A strategic objective is a final objective that has the characteristic to be invariant during the time. A final objective can be decomposed. A means objective can be linked to various means objectives (Fig. 1). It is therefore possible to construct a structure (or hierarchy) of objectives for each decision-maker. To build the most exhaustive possible body of objectives, it is necessary to interview samples of representative individuals of each of the populations susceptible to use the tool (political persons in charge, economical actors, social actors) (Fig. 2). One can merge the structures of obtained objectives to obtain a generic structure of objectives (Fig. 3).

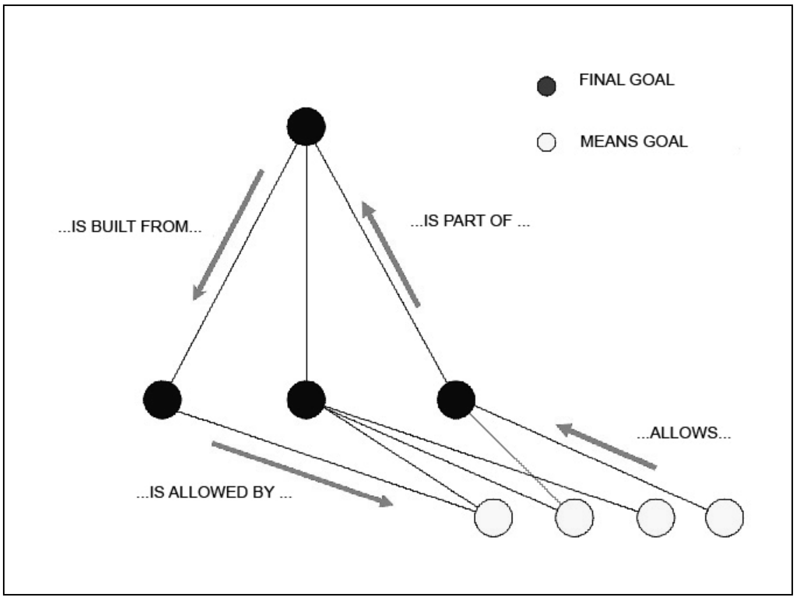

Figure 1 Relation between final and means objectives (Rousval, 2005)

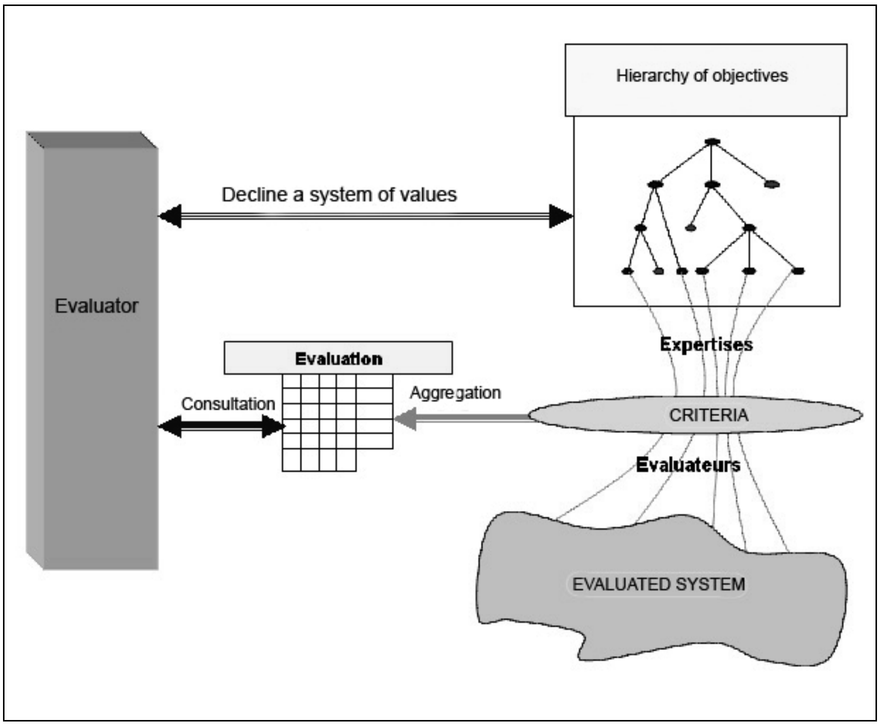

Figure 2 Application of the Value focused approach to our project (Rousval, 2005)

We are characterizing the environmental objectives with a set of dimensions, to allow a better hierarchy, of environmental objectives, by grouping or separating these, according to the dimensions that have kept such as space scale, time scale, scientific discipline, affected target (natural or human environment)…

One will be able to keep several dimensions and to classify them by order of importance, for example, the spatial and the environment scale. According to the choice of the dimensions and of their order, one obtains therefore different tree structures. One of the big interest of this structuring work is to make explicit the proximities or the distances between each of the objectives.

This approach by values offers a number of advantages. It allows an interdisciplinary approach. It allows the definition of a hierarchy of objectives that structures the construction of the system of indicators. It allows "the union" of several hierarchies, in a generic structure, while using a specific algebra. One can thus structure the design of the system of common indicator for a population of decision-makers. It allows balancing objectives by propagating the weight in the hierarchy. It may be used to question and structure the problems of other populations than scientific experts. It may be hybridized while allowing the evaluation using means objectives. At last it is easily applicable to wide contexts, as the one of the sustainable development, or to other disciplinary fields. This tree structure may be used:

- to eliminate the redundancies by aggregating the knots, connecting the indicator to the body of concerned criteria, or by aggregating the arches when the criteria are linked by similar links to the same indicator,
- to aggregate elementary indicators in complex indicators corresponding to the union of several indicators,
- to eliminate the indicators for which there is no available data.
- to spot the link between an indicator and an objective, and to deduce which parameter may allow a validation of the indicator.

This hierarchy of objectives is obtained from a set of interviews with the decision-makers. The interview unfolds itself into two stages. The first stage aims at defining a first body of objectives. One lets the interviewee speaks while making non-directives revivals. Taking some notes allow, then, to do a first census of objectives that appears in the speech of the interviewee. One distinguishes among the answers, the final and means objectives. The second stage aims at exploring the structure of objectives of the interviewee from the quoted elements in the first phase. Thus, one can relate a means objectives quoted to an end objective while asking the question "Why this objective?". From a final objective, one can construct his superior hierarchy (bottom-up) while asking "Why this objective?". To explore in depth the tree of the final objectives (top-down), one will ask "for what this objective is it important?", or "which facets of this objective are important?".

- To master the environment
  - At the planetary scale
    - To preserve an environment in favor of human life
      - To limit the greenhouse effect
      - To limit the climatic change
      - To protect the ozone layer
    - To preserve the natural resources
      - To limit the extinction of natural types
      - To limit the extinction of natural environments
      - To limit the consumption of energy
    - To limit maritime pollution
    - To limit the production of persistent losses
  - At the local scale
    - Concerning natural environments
      - To limit impoverishment of landscapes
      - To limit the mineralization
    - Concerning human environments
      - Concerning public health
        - To limit the effects of the pollution of the air:
          - Of the peaks of pollution
          - Of mean pollution
          - To limit the effects of the accidents
        - To limit the effects of the noise on health
      - Concerning the life quality
        - To limit discomfort :
          - Due to noises
          - Due to smokes
          - Due to the odors
        - To improve the landscape
      - To improve cultural inheritage
      - To improve neighborhoods
      - To preserve the habitats from dust…

Figure 3 – Reduced and filtered hierarchy of objectives (Rousval, 2005)

4. CONSTRUCTION OF THE SYSTEM OF INDICATORS

In this stage, we combine the "value focused approach" for structuring the system of indicators from the hierarchy of objectives, with a definite reconstruction for the selection of the indicators. In this framework, we attempt to associate an indicator to one or several final objectives. When there are several indicators, one is trying to combine or to aggregate the different indicators into an indicator for each objective. For the construction of the systems of environmental indicators, we propose at last two sets of criteria, the first one for the selection of elementary indicators, the second for structuring of the system of indicators.

To choose an indicator characteristic of every objective, a body of definite and informational criteria is defined: type of data, magnitude of the indicator, law of transformation of the impact associated, packaging of the data, measurability, relevance, precision, time scale, space scale…

To build up the system of indicators, the following criteria are defined: homogeneity, exhaustivity, non-redundancy, coverage of the different space and time scales…

5. CHOICE OF AN AGGREGATION METHOD, ELECTRE-TRI.

In the context of the sustainable development and participative democracy, there is no more need today to argue in favor of this stage of aggregation. However, one can say that this aggregation makes it possible:- to simplify (to reduce complexity, or simply to reduce the great number of data in a small number of useful information for the evaluation); to quantify (to model, simulate, build a comprehension of the phenomena, consequences, stakes); and to communicate (help the decision makers to make their own opinion within the framework of a negotiation, an equitable exchange, a critical proceeding.

The disaggregated evaluation of the impacts does not make it possible to determine the most "sustainable" project. Finally the renewal of the political scale of the decision allows proceeding from a strategy of monothematic optimization, to a reasonable compromise between non homogeneous criteria.

Aggregation appears at various levels. In all the cases, it is a matter of integrating specific and more or less heterogeneous information in a coherent body, exceeding a simple concatenation. Three levels are possible:

1) the combination of simple indicators into more synthetic indicators within a given set of themes, by using a mathematical formulation, to bring back for example the indicators on common scales of space and time with an aim of a total evaluation,

2) the concentration in a given theme on a mean indicator by tracking the interrelationships between elementary indicators, with the risk to occult some aspects,

3) on a higher level, aggregation between sets of themes is possible by the establishment of models which lead to condensed information. We must be conscious however about the very political aspect of these models (with the integration for example between the field of the air and that of safety?).

Let's concentrate on this last aggregation of different themes. The transitive methods of aggregation based on the search of a single criterion of synthesis are enough relevant to incorporate indicators corresponding to the same criterion and to even incorporate criteria within the same family of criteria because information can still be regarded as relatively homogeneous up to this level of aggregation (Goger, 2004). In practice, the most widespread methods use a single criterion of synthesis. But that is very limited (total compensation, not of taking into account of the uncertainty and the inaccuracy of the data…).

Contrary to these normative methods set up as absolutes, and independent to the nature of the concerned systems, the multicriteria evaluation proposes "to build up methods and more adapted algorithms (with heterogeneity) of reality" (Roy, Bouyssou, 1993). The methodology of multicriteria aggregation known as partial aggregation does not rely on a mathematical logic, but on its own logic based on intransitivity and the indifference of the preference, and on ability to manage incomparableness. It offers relative and partial evaluations of actions because the approach result from the comparison of the alternatives per pair and not independently and totally. The methods of partial aggregation are especially relevant when information is heterogeneous and covers a more general dimension.

ELECTRE methods, for *ELimination And Choice Corresponding to Reality* (Roy & Bouyssou, 1993), are based on the comparison per pairs. Thus, one compares for example two urban projects to lead to one of the three following conclusions: 1) one is better than the other (without specifying of how much); 2) the two projects are incomparable; 3) the two projects are indifferent.

The multicriteria evaluation contributes to an exhaustive and synthetic census of information, while clarifying the results produced by the collections of indicators specific to each family of themes. The multicriteria evaluation is composed thus of two essential and indistinguishable aspects : the structuring model of information on the one hand and, the relative weighting of these criteria on the other (Goger, 2004).

One of the advantages of Electre methods is the non total compensation of multicriteria aggregation. Indeed, one never tried to carry out a transformation of scale allowing bringing it back to a single criterion, when criteria are corresponding to heterogeneous values. The weights allotted to each criterion are completely independent of the scale of the criterion.

The presence of veto threshold is an additional means to control the danger of the compensation by sanctioning too important variations on criteria whose aspects can be more sensitive.

For all these reasons, we have decided to use of Electre Tri method in our context of assistance to the evaluation. A major asset of the sorting approach used in this particular method is that one does not evaluate the situations compared to other situations, but compared to classes, which can reflect expectations of the decision maker concerning his own objectives.

6. DEVELOPMENT OF A PROTOTYPE ON COMPUTER PROGRAM, IMPACT.

A prototype of computer program, baptized Impact, has been developed in the Access environment.

It allows three modes ranging from the most permissive to the most restrictive:

1) an open mode, for a “local and personalized follow-up”, which makes it possible to have a following-up tool so that the user is able to clarify its personal opinion concerning the sustainability of urban projects,

2) an half-open mode, for a “participative democracy at the level of the city”, which makes it possible to apprehend the environmental situation when designing or following-up a sustainable urban policy,

3) a steady mode, for a “total environmental indicator”, which allows to build up a total indicator related to urban sustainability who is aiming at qualifying the environmental situation of a city, an area or a country in order to compare various cities, areas or countries, in order to communicate

Of course, the evaluators will not be the same ones if one wishes to build up a total indicator or a local and personalized follow-up. It is the same for the role of the experts which will not be represented by the same people according to the context. For example, within the context of a participative democracy, it is useful to leave more freedom to the users. In this case, only the processes of “definition of the structure of objectives”, “definition of the criteria” and “definition of the categories” will not be available: they will be part of a preliminary setting. In addition to the processes of “definition of the assessed system” of “seizure of the performances” and “consultation of the results”, the users will be able thus “to select and balance the objectives” in the hierarchy. The users will thus have a relative freedom to vary the reference frame of the evaluation, without having the knowledge of experts nor to be familiarized too much with multicriteria modeling.

On the level of each decomposable objective of the tree structure, the user can visualize the whole of the under-objectives which are directly attached to him. He can then choose to remove one of these under-objectives. The user can also choose to add to a decomposable objective as many sub-objectives as he wants. A pre-necessity of this process is to have previously carried out the “definition of the structure of objectives” leading to the generic tree. The tool thus offers then a list of candidate items for more general objectives. While positioning on one objective, the user sees then a list of relevant sub-objectives.

It is then necessary to take into account the relative importance of the various objectives concerning the sustainability of urban projects. This weighting is used to allow possible multicriteria aggregation. For that, the tool makes it possible to give to each node of the tree, the weighting for each sub-objective. At the same time as the value of these weights, the user must be able to give the value of the parameter λ of the majority necessary (necessary to Electre), parameter necessary for an aggregation at this level of the hierarchy.

For each criterion, it must be possible to define the values of the indifference, preference, and veto thresholds. This way of defining the thresholds makes it possible to treat at the same time the case of the fixed thresholds (even value of the threshold for all the limit profiles) and of the variable thresholds (value of the threshold which can depend on the limiting profile). A screen capture of Impact is presented in Figure 4.

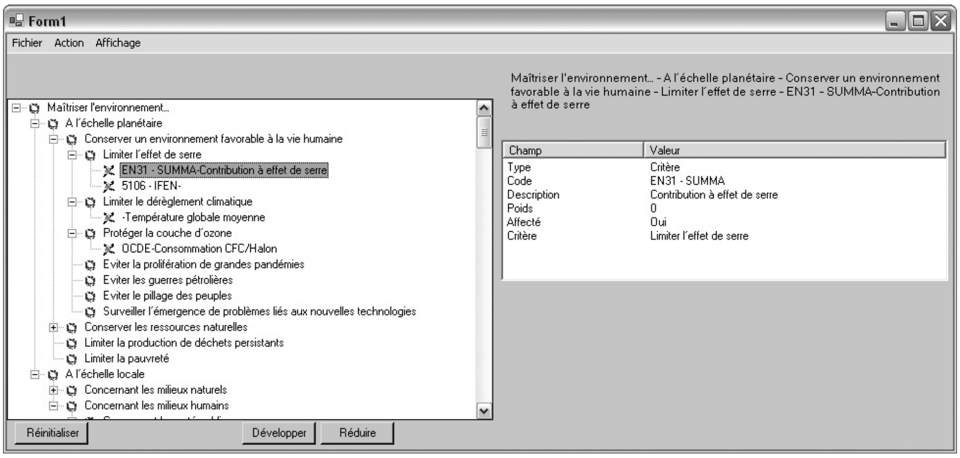

Figure 4: Screen of the Impact tool, presenting part of the hierarchy of objectives related to the limitation of the greenhouse effect

7. CONCLUSION

Based on a critical second reading of the existing systems of indicators, our work proposes a methodological framework for the assistance to an evaluation of sustainable urban projects: 1) a method of choice of the indicators, based on an innovating morphological and structural proceeding; 2) a method for structuring the system of indicators based on defining hierarchies of the objectives of the decision makers, using the "value focused approach", and allowing to merge them in a generic structure; 3)the use of multicriteria decision-making methods to implement this system of indicators in a decisional context.

This work has mainly been developed within the framework of an interdisciplinary project baptized PIE, for Prospective and Environmental Impact, collaboration between the GRECAU of the ENSAT, the LTE of the INRETS (Institut National de Recherche et d'Etude des Transports et de leur Sécurité), and the LAMSADE (Adolphe, 2006).

REFERENCES

Abernot,Y., 1996. *Les méthodes d'évaluation scolaire*, Paris : Dunod.

Adolphe L. & al., 2002. *Sagacités : Vers un système à la gestion des ambiances urbaines*, Rapport final, MENRT, DT N° 99-V0532, 400p., February 2002, Toulouse.

Adolphe, L., Rousval, B., Beaumont, J., Maurin, M., Goger & T., Joumard, R., 2006. *Projet PIE, L'aide à l'évaluation environnementale pour les projets d'aménagement : Applications à un système de transports : Propositions*, Rapport final –Tome 2, Convention INRETS-EAT, July 2006, 120p, Toulouse.

Goger, T., 2004. *Synthèse bibliographique sur l'évaluation des pollutions de l'air générées par le secteur des transports : application au cas de la métropole française*, 64 p., June 2004, Bron.

Keeney, R. L., 1992. *Value-focused thinking: a path to creative decision making*, Cambridge : Harvard University Press.

Maurin, M., 2004. *Problématique pour une approche globale multi-nuisances dans l'environnement*, Inrets- LTE, 16 p, June 2004, Bron.

Rousval, B., 2005. *Aide multicritère à l'évaluation de l'impact des transports sur l'environnement* , Thèse de doctorat, Université Paris IX-Dauphine, Lamsade, Paris.

Roy, B. & Bouyssou, D., 1993. *Aide multicritère à la décision : méthodes et cas*, 250 p., *Université de Paris Dauphine,* Lamsade, Paris : Economica.

UNO, 1992. *Conférence des Nations Unies sur l'Environnement et le Développement, Agenda 21*, Rio de Janeiro.

Yu, W., 1992. *Aide multicritère à la décision dans le cas de la problématique du tri : concepts, méthodes et application*, Thèse de doctorat, Université Paris IX-Dauphine, Lamsade, Paris.

Application of the EcoBlock method to eco-design – electric hand dryers versus paper towels

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ABSTRACT: The EcoBlock method is an environmental performance tool that allows the comparison of products, projects or organizations. It is based on seven indicators: water extraction, resource extraction, land use, greenhouse gases (GHG), other air pollution, water pollution, and waste. A simplified life cycle analysis approach is adopted. The indicators may be aggregated into a single index, inspired in the Ecological Footprint concept. In this case study we compare the environmental performance of two hand-drying alternatives – paper towels or electric dryers. Both techniques present similar results. The pattern of use was found to be a variable of key importance in the comparison: lesser use of towels per drying would tip the balance in favour of the towels, more efficient dryers or lower impact energy sources would tip the balance in favour of the dryers. Electricity consumption proved to be the largest pressure generator in both alternatives.

1 INTRODUCTION

Several instruments and standards have been introduced in the last decades to assess environmental management performance and efficiency of products and companies, such as life cycle assessment (LCA), eco-labels, environmental management systems (EMS) and environmental certificates and register (ISO 14001 and EMAS standards).

Global Reporting Initiative (GRI) has been working on a common framework for environmental, social and economic voluntary reports. It has published guidelines to promote comparability of sustainability reports and to support benchmarking (GRI, 2002, GRI, 2006). The World Business Council for Sustainable Development has also published a list of selected indicators, focusing on eco-efficiency (WBCSD, 2000).

Existing standards are much more management-directed than environment-directed. The result is that, although there is abundant literature on environmental performance, it is far from standardized and little of it is actually applied on day-to-day management (Melo, 2002).

Many countries have regulations imposing environment-related information on specific categories of products, such as energy consumption in appliances and vehicles. Technical notices will have more or less detailed data, but usually the label on the product only bears qualitative information. Typically, labels and technical notices provide little information on environmental effects caused by manufacture, use or disposal of the product. Most eco-labels do not provide quantitative environmental information at all – either the logo is there, or it is not – which makes it difficult to distinguish between two labelled products.

More precise information about environmental effects related to a product can be obtained through LCA which is commonly used for product and process design and for eco-labeling. However, this method is very expensive because it is data-intensive and time-consuming, thus limiting its use; another limitation is that broader issues such as impact acceptability are not usually taken into account (Curran, 1996; Das, 2005).

In short, no method currently in use allows an easy comparison of environmental performance of different products and organizations, nor an easy link between company performance and product labelling.

This paper introduces a method for environmental performance evaluation throughout the supply-demand chain – the EcoBlock method.

2 THE ECOBLOCK METHOD

2.1 *General principles*

The EcoBlock method aims to answer the following brief: to assess the environmental influence of a company or a product with a quantified and life-cycle oriented approach, following a clear and standardized method in a cost-effective way.

EcoBlock indicators were defined under the following general principles:

- Focus on environmental pressure;
- Small number of indicators covering a wide range of environmental issues;
- Correlation with relevant environmental effects, although not pretending to evaluate environmental impacts as such;
- Expression in easily recognizable physical units;
- Ability to describe environmental performance both at product level (goods or services) and at organization level (company or institution);
- Applicability to a wide range of activities and products;
- Data easily gathered from common organization-level EMS or from public record;
- Additive, that is, the sum of indicator values for two separate activities should be equal to the indicator value computed for both activities managed together.

These features are essential to define a method that can be widely applied, standardized and – very important – that allows the transfer of comparable environmental performance information along the supply-demand chain.

The method should be able to support a number of practical applications:

- Standardize environmental labelling of products (goods or services);
- Simplify LCA, because comparable environmental information comes attached – as an "EcoBlock label" – to the products acquired to manufacture the product under study (this will not be as accurate as full LCA, but will be enough for many applications);
- Benchmarking or environmental reporting;
- Implement environmental performance control of suppliers;
- Compare different design solutions for new projects.

2.2 *The EcoBlock indicators*

The literature shows three main types of indicators to assess environment-related performance: management efficiency, environmental impact and environmental pressure. The EcoBlock method adopts pressure indicators because they are environmentally significant and relatively easy to measure and standardize, although they integrate less local or impact information.

The selected indicators are water abstraction, resource extraction, land use, greenhouse gases, polluting emission to water and to air and waste committed to long-term storage. Data to compute EcoBlock indicators can be easily obtained from typical EMS records, such as water and energy use, waste sampling, raw materials listings.

Each indicator is computed from directly measured variables, weighted by an equivalence factor (feq) that conveys the environmental significance of each variable. The equivalence factors are always based on objective criteria, preferably technical or legal standards when available, and reject subjectivity.

EcoBlock indicators are given by the following general equation:

$$I = \Sigma Q_i . feq_i$$

Where: I is the indicator expressed in equivalent units (e.g. greenhouse gas emissions in kg CO_2 eq); Q_i is the measure of a physical quantity of variable i (e.g. emission of a greenhouse gas i); and feq_i is an adimensional equivalence factor for variable i (e.g. the warming potential factor for gas i). All equivalence factors are based on objective criteria, as far as possible based on comparable effects (Macedo, 2005).

Table 1 presents the criteria for equivalence factors for each indicator.

Table 1. EcoBlock indicators and estimation criteria

EcoBlock indicator	Typical unit	Criteria for equivalence factors
Water abstraction	m3	Regional water resources intensity of use
Resource extraction (except water)	kg	Resources availability and renewability
Land use	ha.year	Ecological and social value of territory; role in the water cycle; good or bad agricultural practices
Greenhouse gas emissions (GHG)	kg	Global warming potential
Other polluting emissions to air	kg	Equivalent hazardousness (based on EPER)
Polluting emissions to water	kg	Equivalent hazardousness (based on EPER)
Waste committed to storage	kg	Disposal conditions and hazardousness

It should be noted that the EcoBlock set does not include energy consumption as such. This is of course an important indicator, widely used in management performance. However, energy-related environmental impact is widely variable as a function of energy source and, in current energy systems, it is highly correlated to GHG emissions; it can also easily be expressed as EcoBlock indicators. Therefore we use energy as a proxy to compute the EcoBlock indicators as appropriate.

The EcoBlock method is highly compatible with GRI and WBCSD guidelines. The three systems use environmental performance indicators, especially pressure indicators, and all of them need identical data, allowing companies to reach the objectives of several methodologies with almost the same data. The EcoBlock method has the advantage of simplifying data presentation and comparison because of the reduced number of indicators.

2.3 *EcoBlock Index*

When dealing with eco-design or supplier environmental performance, the seven-indicator EcoBlock vector is not enough: a single index may be called for. It should be noted that this index will not be as consistent as the seven individual indicators.

To express the EcoBlock global index, we have chosen the “global area” under the Ecological Footprint (EF) concept, because it is rather intuitive and well known, and compatible with the EcoBlock logic of standardizing information.

The major differences between the EcoBlock and EF methods are: (i) the EF has a top-down approach, directed at countries and life-styles, while the EcoBlock is aimed at products and organisations; (ii) the EF does not account for variables that are essential in product and organisation environmental performance, such as pollution, water abstraction or mineral resource extraction (Venetoulis, 2004, WWF, 2004). These differences represent as many difficulties when converting EcoBlock indicators into “global area”.

Here we propose a tentative approach to this difficult issue: The “resource” EcoBlock indicators – water abstraction, resource extraction and area – will be converted into global area by assuming that the land available for biological production serves simultaneously those three functions; The GHG indicator is directly converted with the world average of carbon capture assumed in the EF method; The water and air pollution indicators are converted using the concept of the virtual global area theoretically needed to absorb such pollution, in the same way that it is applied in the GHG indicator. We are aware that part of the pollution is actually absorbed or rendered innocuous by real land, already accounted for. For simplicity, we have compared GHG and other pollution according to the report limits of EPER – the European Pollutant Emissions Register. The long-term waste storage is converted by relating it to an estimation of land influenced by such storage.

In this exercise, we have used the conversion coefficients indicated in Table 2.

Table 2. Conversion coefficients to compute the EcoBlock index

Water (glob m^2/m^3)	Resources (glob m^2/kg)	Land use (glob m^2/m^2)	GHG (glob $m^2/kgCO_2$)	Oth.air pollut. (glob m^2/gNO_2)	Water pollut. (glob m^2/gCOT)	Solid waste (glob m^2/kg)
4.5	5.5	0.16	3.0	3.0	2.8	0.1

Because mineral extraction and most of the pollution are not accounted for in the EF, when we convert all EcoBlock indicators into “global area”, the final result will usually be higher than using the classical EF method. This is, indeed, an intended feature of the EcoBlock global index, although research is underway to establish a more robust relationship.

2.4 *Case-studies*

The EcoBlock method has been extensively tested in Portugal, with several types of case-studies. A national survey was conducted among the construction business in Portugal, covering the whole life cycle of materials and buildings. Results from this survey have been reported before (Melo, 2002).

3 CASE STUDY: ELECTRIC HAND DRYERS VERSUS PAPER TOWELS

3.1 *Scope and general criteria*

The aim of this case study was to compare the environmental performance of electric dryers and paper towels in the sanitary facilities of shopping centers. Data were provided by the shopping center operator, Sonae Sierra, and from available literature.

Several shopping centers were analyzed, although one of them, located in Lisbon, was selected as the main case study due to overall consistency of available data and because it uses both paper towels and electric dryers. Data on visitors to shopping centers were available. It was assumed that one out of three visitors will use the W.C. and hence will wash and dry his/her hands.

Environmental performance data, relevant for the life cycle assessment of both technologies (electric dryers and papers towels) were gathered from Portuguese national statistics, reports and literature. The results are deemed to be representative for Portugal. The analysis and aggregation of environmental information followed the EcoBlock method as described above.

3.2 *Electricity generation*

Environmental pressure from electricity production and distribution was computed from the following sources and criteria: official national data on atmospheric pollution from thermal power plants and oil refineries (APA, 2007); official electricity production and distribution data, including amount of fuels consumed (DGEG, 2007); pollutant emissions from coal extraction from Australia (one of the major coal exporters to Portugal); atmospheric emissions from the maritime transport of coal and oil; water consumption in power plants (INAG, 2004); water evaporated from reservoirs used for electricity generation and land occupied by reservoirs (INAG, 2007); waste generated by power plants.

Power plant construction, general maintenance and non-consumptive uses of water were not included in the analysis.

The results are shown in Table 3.

Table 3. Environmental pressures from electricity as acquired from the public electrical grid in continental Portugal (EcoBlock indicators)

Water (dm^3/kWh)	Resources (g/kWh)	Land use (dm^2/kWh)	GHG (g CO_2/kWh)	Oth.air pollut. (g NO_2/kWh)	Water pollut. (g COT/kWh)	Solid waste (g/kWh)
14.5	196	7.10	589	7.11	0.0282	0.760

3.3 *Electric dryers*

Only the electric dryer model in use in the shopping centers selected was analyzed. An estimation of composition of the apparatus and environmental implications of its manufacturing was performed, based on technical specifications and available literature on materials extraction and production. Major materials are steel, copper, aluminum and plastics. An average of five years life time for a dryer was assumed, based on maintenance registers.

Electricity consumption of the dryer was assumed as nominally declared by the manufacturer, per cycle of operation. "Phantom consumption" at idle time due to the electrical wiring was not measured or considered.

3.4 *Paper towels*

The paper towels were traced back to paper and pulp manufacturing and raw material origin, both wood and recycled paper. Environmental management data from industry and forestry operations were used (Renova 2005, CELPA 2005, Portucel Soporcel 2005, Baluarte 2004, APA 2007). The following environmental pressures were thus computed: water consumption, emissions of GHG, other atmospheric pollution, water pollution, wastes, fuel consumption and electricity consumption on the industrial plants; primary extraction of woods, mostly eucalyptus, in terms of land use and biomass extraction. Packaging, transport and waste disposal of the towels were included in the analysis, as was maritime transport of imported raw materials; percentages of wood pulp and recycled paper pulp are real.

The steel towel case manufacturing was also considered.

Energy consumption of forestry operations, raw material transportation within Portugal, industrial plant construction and maintenance, were not considered.

Based on a limited inquiry to users, it was assumed that, on average, each user consumes two towels per usage.

4 RESULTS OF CASE STUDY

4.1 *Comparing electric dryers and paper towels*

The environmental pressures of electric dryers and papers towels were aggregated throughout the life cycle according to the seven EcoBlock indicators and expressed per use (that is, per dryer cycle or per two towels). The results are presented in Tables 4 and 5.

Table 4. Environmental pressures per use of electric dryer or water towels (EcoBlock indicators)

	Water (dm^3/use)	Resources (g/use)	Land use (dm^2.year/use)	GHG (g CO_2/use)	Oth.air pollut. (g NO_2/use)	Water pollut. (g COT/use)	Waste (g/use)
Towels	0.696	3.86	0.497	14.3	0.106	0.0499	0.594
Dryers	0.308	4.19	0.151	12.6	0.151	0.00060	0.0161

Table 5. Environmental pressures per use of electric dryer or water towels (EcoBlock index, all values expressed as "global dm^2.year/use")

	Water	Resources	Land use	GHG	Air pollut.	Water pollut.	Waste	TOTAL
Towels	0.31	2.1	0.08	4.3	31.8	14.0	0.01	53
Dryers	0.14	2.3	0.02	3.8	45.3	0.17	0.00	52

Results indicate that, for a typical usage, the environmental pressure of electric dryers and paper towels is very similar — a difference of less than 2%.

In both cases the largest contributor to the "ecological footprint" is acidic and other air pollution; followed in the case of the towels by water pollution; GHG and material resources also play an important role.

4.2 *Comparing phases of life cycle*

The method allows for a simple comparison between the pressures caused by different phases of the life cycle. Results are shown in Tables 6 and 7.

Table 6. Relative weight of different phases of life cycle of paper towels.

Life cycle phase	Contribution
Box manufacture	0.0%
Paper recycling	0.4%
Eucalyptus production	1.7%
Pulp production: local pressure	31.9%
Pulp production: electricity acquisition	5.7%
Paper production: local pressure	9.8%
Paper production: electricity acquisition	48.7%
Disposal (landfill)	1.9%

Table 7. Relative weight of different phases of life cycle of electric dryers

Life cycle phase	Contribution
Dryer manufacture	0.1%
Electricity consumption in use	99.9%
Maintenance	0.0%

Results show that the main contributor to environmental pressures is electricity production, followed by air and water pollution on site for pulp and paper manufacture.

4.3 *Sensitivity analysis to user's practice*

Because there was no information available on actual user's practice, we have performed a sensitivity analysis to different uses of towels and dryers. We also considered the possibility of using dryers with half the drying time, because the dryers tested were of fixed drying time, and apparently many users do not use the full drying period. Results are shown in Table 8. Note that our previous assumption was that the average user would spend one dryer cycle or two towels.

Table 8. Sensitivity analysis to user's practice and equipment efficiency

No. of towels per use	1	2	3	4
EcoBlock index (global dm^2.year/use)	26	53	79	105
No. of dryer cycles per use	0.5	1	1.5	2
EcoBlock index (global dm^2.year/use)	26	52	78	103

Results show that the environmental performance is highly dependent on both the equipments efficiency and the user's practice. A comparison between actual consumption of dryers with or without sensors would be interesting. A "softer" electricity source, such as solar energy, would greatly decrease the environmental pressure, especially of the electric dryer.

4.4 *Sensitivity analysis to conversion coefficients*

As referred above, the conversion coefficients used to compute a global index from the seven indicators are tentative. To test the robustness of the coefficients assumed in this exercise, a sensitivity analysis was performed by doubling and halving in turn each coefficient.

The results show an oscillation between –15% and +21% as referred to central values. This, although not irrelevant, is clearly inferior to both the margin of error of base data and to the sensitivity of results to user's practice. We consider therefore that this issue, although it merits undoubtedly further research, is not a limitation to the conclusions of the present case study.

5 CONCLUSION

EcoBlock indicators have the advantage of being clearly defined, easily measurable and verifiable.

The major innovation and advantage of EcoBlock method relies on two aspects: (i) the concept of environmental performance transfer over the productive chain, relating complementary data at organization and product level; and (ii) an objective method of data aggregation that allows standardization and diminishes the total number of indicators while encompassing a large range of environmental issues. Sensitivity analysis in this and other case studies suggests a good robustness and reliability of the method.

The application of the method becomes more reliable as data availability increases, both at organization level (with e.g. environmental management systems) and with official statistics. Because the EcoBlock method relies heavily on standard organization and public information, rather than specific inventories, its usability may be expected to improve as such sources of information become more available and standard.

On the case study at hand, a number of interesting conclusions may be drawn.

First, in the current state of technology and practice, paper towels and electric dryers have very similar environmental effects.

Second, the single largest contributor to the environmental pressure is electricity production. This is obvious in the case of electric dryers but is also true in the case of paper towels.

Third, the factors that most affect the performance of one technique or the other are the actual practices of the user and the energy source. Hence, a cleaner source of electricity such as solar energy would go a long way towards the reduction of environmental pressures.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

APA. 2007. National inventories of GHG and EPER. www.iambiente.pt.
Baluarte. 2004. Declaração Ambiental.
CELPA. 2005. Boletim Estatístico.
Curran, Mary Ann. 1996. *Environmental Life-Cycle Assessment*. McGraw-Hill. USA.
Das, Tapas K. 2005. *Towards Zero Discharge. Innovative Methodology and Technologies for Process Pollution Prevention*. Wiley Interscience. Jonh Wileu & Sons, Inc., Publication. New Jersey.
DGEG. 2007. Energy statistics. www.dgge.pt.
GRI. 2002. *Sustainability Reporting Guidelines*. Global Reporting Initiative. Amsterdam.
GRI. 2006. *Sustainability Reporting Guidelines – version 3.0*. Global Reporting Initiative. Amsterdam.
INAG 2004. *Plano Nacional da Água*. www.inag.pt/inag2004/port/a_intervencao/planeamento/pna/pna.html
INAG. 2007. Large dams in Portugal. http://cnpgb.inag.pt/gr_barragens/gbingles.
Macedo, L., Melo, J. Joanaz 2005. Environmental performance evaluation through the "EcoBlock label". Sustainable Management in Action - SMIA 05, Geneva, Switzerland.
Melo, J. Joanaz, Pegado, C. 2002. EcoBlock – A method for integrated environmental performance evaluation of companies and products. In: *Proceedings of the Fifth International Conference on Eco-Balance*, 399-402. The Society of Non-traditional Technology, Tsukuba, Japan. November 2002.
Portucel Soporcel. 2005. Relatório de Sustentabilidade.
Renova. 2005. Declaração Ambiental.
Venetoulis, J., Chazan, D., Gaudet, C. 2004. *Ecological Footprint of Nation*. Redefining Progress. Oakland.
WBCSD. 2000. *Measuring Eco-efficiency*. A Guide to Reporting Company Performance, World Business Council for Sustainable Development. Geneva.
WWF. 2004. *Living Planet Report 2004*. Switzerland.

More information: http://gasa.dcea.fct.unl.pt/ecoblock; and http://www.ecoreporting.com

Life Cycle Costing as part of decision making - use of building information models

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ABSTRACT: Building Information Modelling (BIM) is a new approach for being able to describe and display the information required for design, construction and operation of buildings. More extended use of BIMS, with the development of Information Delivery Manuals (IDMs) for environmental assessments, energy calculations and LCC, ensuring more automatically data flow between different data bases, calculation tools and Building Information Models (BIM), will simplify the use of LCC in design. More extended use of LCC, and storing the results for future use may also improve the Facility Management. Several projects have dealt with cost information flow, as information exchange between the BIM and LCC-tool and improving cost data bases, simplifying the data access as well as storage possibilities to ease and extend the use of LCCA. This paper will present the current stage of the different project aiming at increased use of LCCA by use of BIM and IDMs.

1 INTRODUCTION

Building and construction projects may benefit by use of Life Cycle Cost Assessment at early stage of the design process, the results contributing to decision support taking both investment and operation costs into account. Qualitative good results demand good input data to the calculations, even at stages where few decisions are taken.

Building Information Modelling is a new approach for being able to describe and display the information required for the design, construction and operation of constructed facilities. It is able to bring together the different threads of information used in construction into a single operating environment thus reducing, and often eliminating, the need for the many different types of paper document currently in use.

Realistic LCCA, as a good basis for decision making, requires easy accessible data in all phases from brief to construction, where statistic information, key numbers and experience data is valuable information. A well defined classification system for the categorisation of costs and other input data is important for a successful use of LCCA. Increased use of LCCA at several stages in the decision process also requires increased data exchange and storage possibilities. Extended use of LCCA may improve the decision process towards more economic as well as environmental and energy efficient buildings.

More extended use of Building Information Models (BIM), with the development of Information Delivery manuals (IDMs) for environmental assessments, energy calculations and LCC, ensuring more automatically data flow between different data bases, calculation tools and Building Information Models (BIM), will simplify the use of LCC in design. More extended use of LCC, and storing the results for future input to Facility Management may also improve the Facility Management.

Easy access to comparable data gives the building owners' possibilities to benchmark their buildings, with emphasis on energy use and operation cost. This will lead to more focus on operation of buildings, as well as improvement of energy efficiency.

Several projects have worked with improves cost information flow, as information exchange between the BIM and LCC-tool and improving cost data bases, both key number bases and cost data bases related to building parts, and further information flow from FM-information into cost data bases. Key numbers may be found from statistical treatment of collected data. For instances energy use/energy costs pr m2, cleaning costs pr m2, or cost used for management or maintenance for different building categories (function and age). Key numbers may be used for benchmarking, as all users may compare their actual data with the collected data, and hence know how their use and management of the building is compare to others.

2 BUILDING INFORMATION MODELING

2.1 *IFC, BIM, and buildingSmart*

The development, maintenance, implementation and dissemination of Industry Foundation Classes, IFC and IFC enabled products is part of the buildingSMART initiative of the International Alliance for Interoperability, IAI, and its affiliated organizations and companies. “buildingSMART is integrated project working and value-based life cycle management using Building Information Modeling and IFCs”

The purpose of IFC as part of the buildingSMART initiative is "enabling interoperability between AEC/FM software applications". It is embedded in a broader scope of achieving beneficial change in industry, using Building Information Modeling (BIM) and IFCs as the trigger to smarter ways of working. IFCs target both the software development community and the practitioners in the AEC/FM industry.

- Developing software that benefits from the international, single and interoperable schema of construction elements, specifications and structures is the task of software companies. Software developers have to understand the detailed structure, content, and processing of IFC.
- Applying interoperable and IFC compliant software within construction processes requires users that are knowledgeable about their processes, the exchange requirements within each process, and its relevance to the technical, commercial and legal side of the operation. Practitioners have to understand how to map general concepts or parts of the IFC to the detailed exchange requirements within their projects and how to assess and use IFC compliant software.

IFC and use of BIM will have great potential for cost reduction and utilize effects in the value chain at least in these areas:

- Focus on the customers and end-users requirements within the building process and life cycle phases.
- Re-engineering of the building process with new opportunities for new and existing actors.
- A comprehensive and common international knowledge model database with standardized ICT tools, objects and communication rules and available best practices examples.
- Cost reduction and better project economy in the supply chain, between the suppliers and the contractors.
- Improved possibilities for early stage analysis about: best practice design, construction cost, energy consumptions, environmental impacts and lifecycle cost.

2.2 *Planning and construction process*

Planning and design of buildings and constructions are phases in a process with many actors and an intensive process of sharing and/or repeating information. Figure 1 shows the information flows between the different actors in a construction process, both a traditional process and by use of Building Information Models.

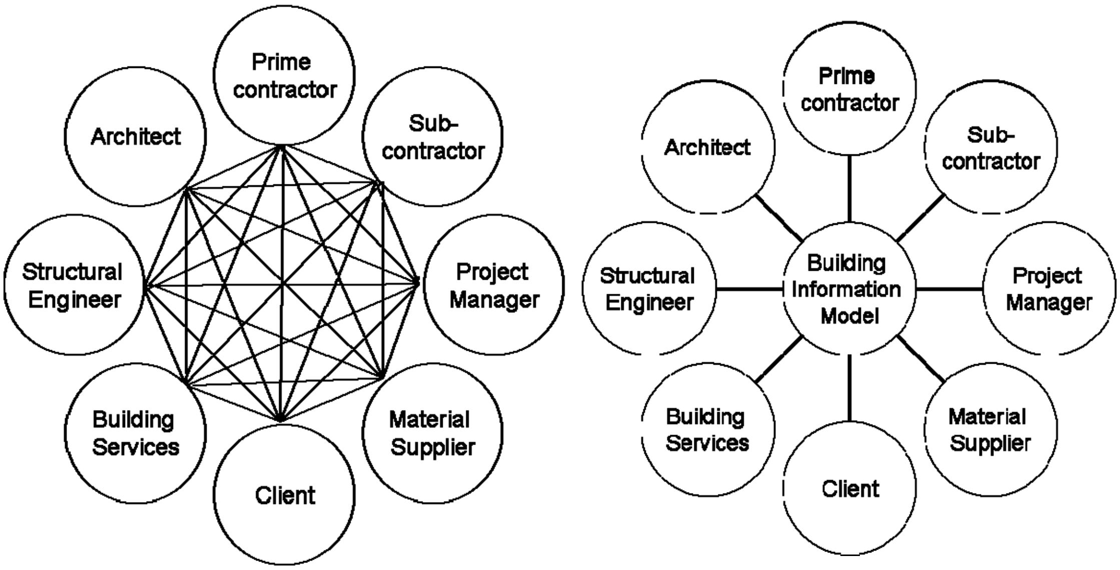

Figure 1 Information flow between actors in a traditional project and by use of Building Information Model

When all actors have access to the same information, and the possibility to transfer information from the model to the different calculation and analysis tools, all decision making can be based on up to date analysis of the interesting aspects. More analysis may be done in an early phase of the project, while it is still possible to make changes. Analysis may also be done on different alternatives.

Life cycle costs analysis or assessment may throughout all stages be done by use of information in the BIM, information from different cost databases, and with application that is ifc compatible ensuring a seamless data transfer. Results from the analysis are then fed back to the BIM for use in other analysis, decision making or for later use in facility management in the operation phase.

3 LIFE CYCLE COSTING ASSESSMENT

3.1 *Life cycle costing used in decision making*

Life cycle costing assessment should benefit that the perspective of decisions is moved from investment costs to the total costs for the whole life cycle of the building or constructed work. Life cycle costing should not be used with the intention of decreasing the costs, but for ensuring the lowest cost over the life cycle when still fulfilling the performance requirements (functional and technical requirements). The assessment should also be used to show the estimated yearly costs before investments are done.

Using LCC as part of decision making requires good accessibility to reliable input data to the analysis at all stages of the planning and design process, starting with generic information (statistic, key numbers) to more and more specific information. Reliable statistic and generic information can be produced by collecting actual costs from management of buildings, using specified and standardized cost classification. The Norwegian Standard NS3454 Life cycle costs for building and civil engineering work – Principles and classification (NS, 1997) does, as also similar German and Austrian standards, give a cost classification system. The Norwegian database owned by Network for benchmarking yearly collect actual costs from their members' buildings, then providing a database with costs to be used for benchmarking and input to LCC calculations. Table 1 shows the main categories in a proposition to a new common Nordic standard.

Table 1 Cost classification for Life Cycle Costs in proposition to new Nordic standard

No.	Main Item	Definition	Sub-categories
1	Capital	All investments towards completion including	11 Project costs 19 Remaining costs

		decommissioning by the end use of the facilities	
2	Administration	Activities for administration, required payments and insurance costs	21 Taxes and fees 22 External costs 23 Administration and management 24 Insurance 29 Various
3	Operation	Include daily, weekly and monthly activities that are repetitive within a one year period for building and technical installation systems that shall satisfy given functional demands and requirements	31 Operation and inspection executed by own employees 32 Operation and inspection executed by external companies 37 Outdoor operation and inspection executed by own employees 38 Outdoor operation and inspection executed by external companies 39 Various
4	Maintenance	Include all activities and efforts put forward in a period of more than one year. For example, planned maintenance, replacement and emergency repairs, so that the building and technical systems satisfies the original level of quality and functional requirements.	41 Periodical maintenance of exterior of the building 42 Periodical maintenance of internal of the building 43 Replacement of exterior 44 Replacement of interior 45 Emergency repair work for exterior 46 Emergency interior repair 49 Outdoor
5	Developing	Includes activities as a result from change in demand from core activities, the authorities, total refurbishment, or all activities to raise the construction standards in relation to the original level	51 Development and upgrading of exterior of the building 52 Development and upgrading of internal of the building 59 Development and upgrading outdoor
6	Consumption	Consumption includes resources in terms of energy, water, and waste handling	61 Energy 62 Water and Drainage 63 Waste Handling 69 Various
7	Cleaning	All activities inside and outside for satisfactorily meeting cleaning demands	71 Daily/Periodic 72 Main cleaning 73 Special cleaning 74 Window cleaning 75 Façade cleaning 79 Outdoor cleaning
8	Service	All non-building related activities in support of the core activity	81 Security and safety 82 Reception/switchboard 83 Mail 84 IT service 85 Moving 86 Catering 87 Accessories/copying 88 Administrative support 89 Furniture and inventories

Life cycle costing can be presented as Net Present Values or Net Present costs, while other options are available, as Annual Cost or Annual Equivalent Value, or Payback. Definition of cost categories and calculation rules are given for example in ISO/DIS 15686-5 “Buildings and constructed assets – Service life planning. Part 5 – Life cycle costing” (ISO, 2006).

3.2 *LCC in different project stages*

The standard exchange requirements published in IDM are identified against project stages defined within the Generic Process Protocol (GPP) (Michail Kagioglou et al, 2000). These are identified below with their stage number as used in the exchange requirements documents, description and definition from the GPP. Stage 10 (disposal) is a modification to the standard GPP list to handle the final stage of a project lifecycle. These are shown in Table 2

Table 2 Project stages defined in Generic Process Protocol

Stage	Description	Definition
Pre-project stages		
0	Portfolio requirements	Establish the need for a project to satisfy the clients business requirement
1	Conception of need	Identify potential solutions to the need and plan for feasibility
2	Outline feasibility	Examine the feasibility of options presented in phase 1 and decide which of these should be considered for substantive feasibility
3	Substantive feasibility	Gain financial approval
Pre-Construction stages		
4	Outline conceptual design	Identify major design elements based on the options presented
5	Full conceptual design	Conceptual design and all deliverables ready for detailed planning approval
6	Coordinated design (and procurement)	Fix all major design elements to allow the project to proceed. Gain full financial approval for the project
Construction stages		
7	Production Information	Finalise all major deliverables and proceed to construction.
8	Construction	Produce a product that satisfies all client requirements. Handover the building as planned.
Post-construction stages		
9	Operation and maintenance	Operate and maintain the product effectively and efficiently.
10	Disposal	Decommission, dismantle and dispose of the components of the project and the project itself according to environmental and health/safety rules

3.3 *Geometric and spatial structure*

A spatial project structure might define as many levels of decomposition as necessary for the building project. The costs might be added to any element. Elements within the geometric and spatial project structure are:

- site as IfcSite
- building as IfcBuilding
- storey as IfcBuildingStorey
- space as IfcSpace
- building elements as IfcBuildingElement
- components as IfcBuildingElementComponent
- products as IfcProducts

The structure from site, building, elements, components, and products is further used as cost levels.

3.4 *Performance requirements*

Before doing the life cycle cost assessment it is important to have the performance requirements for the facilities to study. The BIM makes it possible to start the process by having a performance requirement model, which later will be used as part of the checking systems, analyzing which requirements that are fulfilled. The performance requirement model will then be further developed and improved throughout the planning stage. The alternatives compared should always fulfill the performance requirements.

3.5 *Intangible costs – extra value*

Intangible costs is usually not included in LCC, but if possible, value might be given and used as an additional part of the decision process. There might also be given values to extra functions or performances, for instance based on experience, but these values should also only be used as an additional part of the decision process.

3.6 *Examples of LCC in different stages*

LCC in pre-project stages is used for studying the consequences of the performance requirements, before any decisions are made. In the early stage of a project, LCC forecasting may use 'benchmark costs' based on historical costs of previous projects. As design evolves and more detailed information becomes available, benchmarks should be substituted with first principle project-specific estimated costs. Often (but not always) life cycle costing will include a single lump sum which represents all the acquisition costs (e.g. the purchase cost) and may also take account of residual value/disposal costs. The analysis in pre-project stages are aiming at assign different alternatives, where continuing as to day may be one option.

One example is increasing school capacity, where the alternatives may be as follows:

- Continuing as today – some pupils sent to other schools
- Extension of existing school, with or without refurbishment of existing building
- New school in addition to existing school – different location
- New school with higher capacity instead of existing building

Comparing the different alternatives it is important to include differences in costs for running the core business (school), not only the building related costs. This may be included in category 8 costs. Table 3 shows examples of sources for information at this stage, number of m2 may be statistic information based on number of pupils. At this stage the comparison is on main alternatives, not design, construction, or installations. The main cost differences may be in category 8, the decision at this stage might not be building related, but taking into account the differences in costs for the core business. Almost all costs are statistic or historic information, updated for extra m2. All costs as on building or site level.

Table 3 Cost categories and sources for information

Cat.	Alt 0	Alt 1a – 1b, 2, 3, and 4
1	No investments	Generic information – investment costs pr m2 for new buildings and refurbishment
2	Existing costs	Existing costs – corrected for number of m2 or key number for costs per m2 or per pupil
3	Existing costs – higher costs in future?	Key number for school buildings, per m2, for building from same time period – and new buildings
4	Existing costs – higher costs in future?	Key number for school buildings, per m2, for building from same time period and main materials – and new buildings
5	No costs	Upgrading of existing building – key numbers for upgrading buildings from the same period
6	Existing costs	Existing costs and key numbers, energy use as in regulations
7	Existing costs	Key number for school buildings, per m2, for building from same time period and main materials – and new buildings
8	Existing costs Transport costs pupils to other schools Costs for pupils at other schools	Existing costs Changes in use of staff compared to Alt 0, need for more teachers, need for more administrative staff if 2 schools etc.

The calculated life cycle costs are used for choosing alternative – more than one if more detailed comparison is necessary to decide – and to get financial approval. If the costs for all alternatives are too high, this is also the stage for redefining the requirements.

As alternatives it is possible to add extra requirements to the alternatives, for instance a swimming pool. Results from alternatives with or without swimming pool should then not be directly compared, but results used for deciding whether the value of the gain swimming pool exceeds the costs.

3.7 *Life cycle costing in conceptual and design stage*

With a database for facility management costs from existing buildings, where building information as age, main construction systems and materials, types of ventilation etc are given, statistic cost information can be tagged with those technical and functional descriptions.

When comparing different designs and technical installations, where the performance requirements always are fulfilled, many calculations still can be based on statistic information. Cost information might still be used as input on building levels, adding some specific information on system or building part level. Examples of relevant input costs, sources and level where they are to be used are shown in Table 4.

Table 4 Examples of relevant costs and level to be used in LCC in design stage

Cost category	Site/building	Room	Element	Component	Product (usually not selected at this stage)
Capital	Investments aggregated from element. Demolition costs		X Cost data bases	(X) Cost data bases	Cost data bases
Administration	X Key numbers				
Operation	X Key numbers				
Maintenance	Key numbers, "corrected" for statistic information fro certain systems and installations		X Statistic information/experience	(X)	
Developing	X				
Consumption	X Regulations or energy calculations for different designs	(X) Separate calculation for certain rooms/functions?			
Cleaning	X – aggregated from room, key numbers	(X) Key numbers or experience for different levels of cleanliness			
Service	X				

Information about elements, areas, numbers, etc will at this stage be extracted from the design model(s). As the table shows, statistic information on building level, where tagged information is used, will be sufficient for LCC at early stage, comparing different main alternatives. The LCC calculations will then also give for instance total and annual cost for the whole building life cycle.

Further in the design stage, as more and more information can be linked to elements, components and products, mainly investments and maintenance.

4 CONCLUSION

Using BIMs, from performance requirement models to design models, and different ifc compatible cost data bases, LCC calculations will be more useable as input data will be available and can be automatically transferred between the model, databases and applications. LCC can be done at every stage, and hence be a part of the decision making process early in the design process.

REFERENCES

Standard Norway (1997) NS3454 Life cycle costs for building and civil engineering work – Principles and classification.

ISO (2006) ISO/FDIS 15686-5 Buildings and constructed assets – Service life planning Part 5 – Life cycle costing.

Michail Kagioglou et al (2000) Rethinking construction: the Generic Design and Construction Process Protocol. Engineering Construction and Architectural Management. Vol. 7 Issue 2 June 2000

A Fuzzy-Neural Tree Knowledge Model for the Assessment of Building's Transformation

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ABSTRACT: One building is more flexible in terms of use than the other and to determine how much a building 'X' is more flexible than a building 'Y' is a rather complex task. This research focuses on houses for the elderly in terms of future use, since the requirements have changed and many of the existing buildings do not meet new requirements. To asses a transformation of a building one needs to take many aspects into account such as: spatial transformation, technical transformation and their various sub-aspects. There are also different future use scenarios, defined by Netherlands Board for Healthcare Institutions, and one scenario is more suitable for a building than another. Firstly, in order to deal with this complex topic there is a need for a systematic approach where all relevant aspects determining a transformation value of a building will be defined. Thereafter, fuzzy-neural tree structure is used as a suitable method for knowledge representation and knowledge modeling.

1 INTRODUCTION

Currently there is a rising problem of demographic aging in the Netherlands. The demographic ageing is a consequence of aging of the post-war generation. These are the so-called baby-boomers that were born between 1945 and 1955. At this moment 1 million people are 75 years and older. In 2050, according to the expectations, this number will increase up to 2.2 million (CBS, 2003). This demographic ageing has, among other things, a significant impact on a healthcare system. Since people are in general becoming older there is a higher chance that the elderly illnesses will increase as well. In the coming years there is a rapidly increasing demand for houses for the elderly and nursing homes (Bouwcollege, 2003). Next to such increasing demand there is at the same time a concern regarding environmental impact. There are many ways in which a construction industry can reduce the impact of buildings on the environment. One of the possible ways is to reduce the amount of building waste by demolishing less buildings. Even when a building has reached the end of a functional lifetime it does not mean that a building cannot be efficiently upgraded to meet new requirements or change a function and therefore adapt for another use. In the Netherlands such issues play an important role and this paper deals with finding the most suitable scenario for a building in terms of future use so that an optimum can be achieved between demand and environmental impacts.

2 RESEARCH BACKGROUND

In 2005 the Netherlands Board for Healthcare Institutions, further in the text will be reffered to as Bouwcollege, conducted a monitoring research. This study provided the most recent overview of the technical and functional quality of the existing buildings in the sector 'Houses for the elderly and Nursing homes' (Bouwcollege, 2005).

The main goal of the monitoring study was to establish untill which extend the existing buildings met user requirements in terms of functionality and use and at the same time to determine what the technical quality of the existing buildings was. The results were classified into three colors wherein each color represented an advice and indicated a possible future action. These colors were:

- green (a building satisfied the requirements or only minor improvements were needed)
- orange (a building needed to be upgraded and more improvements were necessary)
- red (a building did not satisfy the requirements and a question was whether these buildings had any future).

Figure 1 gives an example of the monitoring scores for three buildings, where two buildings obtained a red score and one had a green score. Later in the paper these results are combined with the results obtained by a knowledge model (for reference see *figure 5*).

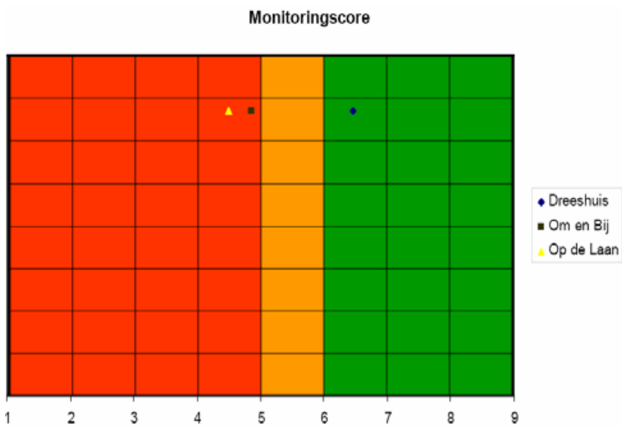

Figure 1: Representation of the monitoring results for three buildings (Nauta, 2007)

One of the conclusions from the monitoring study was that a majority of buildings (63%, meaning 652 buildings) had one or more lacks which should be taken care of within the coming years. These buildings had a green score. In total 36% of the institutions (349 buildings) had an orange and red score. Especially these buildings were problematic, since it seamed that for some of them the demolition was the only possible solution. Such decision would result in a large scale capital demolition, decrease of available places for the elderly and would as well have a high negative impact on the environment. Therefore it was necessary to research other possibilities such as changing functions but still remaining within the healthcare domain in order to meet the growing demand for places in nursing homes or houses for the elderly. So the next step was to investigate whether the buildings that had a red score could be upgraded to another (healthcare)function. In that respect it was necessary do define possible future use scenario's. Since most locations of the existing houses for the elderly had mostly a central location most of these healthcare institutions wanted to keep these locations in the future as well. Having all these issues in mind, Bouwcollege proposed four possible future scenarios where the existing houses for the elderly would be converted to:

1. nursing home (group of 6 to maximum 10 persons in a group, min. 15m^2 per bedroom)
2. nursing home (individual units, minimum 18m^2);
3. new apartments for elderly, according to new requirements (45 m^2)
4. apartments-for-all (separating living and care, apartments minimum 60m^2).

In order to make an end to an endless discussion about how flexible a particular building is in terms of future use, it was necessary to develop a tool that would provide an answer regarding the transformation capacity of the existing houses for the elderly. For this purpose, a systematization of all aspects determining transformation value of the buildings was necessary and thereafter suitable techniques are required for knowledge representation and modeling. Further in the texts, research methodology will be explained followed by knowledge modeling, with the main focus on knowledge modeling part.

3 RESEARCH METHODOLOGY

In the monitoring study Bouwcollege already obtained a lot of information regarding the buildings such as their typology, construction method/materials used, dimensions etc. What was still missing was the systematization of aspects that determine a transformation potential of buildings. Based on a PhD thesis of E. Durmisevic (2006a), graduation thesis of Schunselaar (2006), and in constant feedback from the Bouwcollege, E. Durmisevic systematized aspects related to the transformation capacity (*table 2*). These aspects were first of all divided into two main groups and thereafter further subdivided in other categories. A list of all nineteen aspects determining the transformation value is given in *table 1*:

Table 1: Aspects determining transformation capacity of a building

TRANSFORMATION VALUE (TV)			
SPATIAL TRANSFORMATION (ST)		TECHNICAL TRANSFORMATION (TT)	
POSITIONING (PO)	DIMENSIONING (DI)	DISASSEMBLY (DIS)	CAPACITY (CA)
Minimal dimensions on a building level	Hallway width/position of load bearing construction	Main installation network	Capacity of the installation ducts
Load bearing construction: floor-to-ceiling height/floor thickness	Hallway width/position of installations	Distribution network	Capacity of the load bearing construction in relation to new (wall) openings
Load bearing construction: depth/grid system	Positioning of the vertical installations	Separation of separation walls	Capacity of the load bearing construction in relation to hallway width
Load bearing construction: dimensioning/ventilation system	Direction of the vertical installation ducts		Future expansion of the building
Hallway width	Clustering of vertical elements		Capacity of the elevators/stairways
Façade openings: dimension/room depth			

In first instance to be able to generalize to certain extend, the buildings were subdivided into four major types, being:

- single corridor
- double corridor
- core/central corridor
- gallery

For each of these typologies and each scenario a minimum spatial requirements were determined both on a building level as well as on a unit level. Thereafter, based on extensive spatial analysis, having in mind four different future scenarios and related requirements, various spatial and technical solutions were graded on a scale between 0 and 1. An example of a grading is shown on the example of sanitary area (*figure 2*).

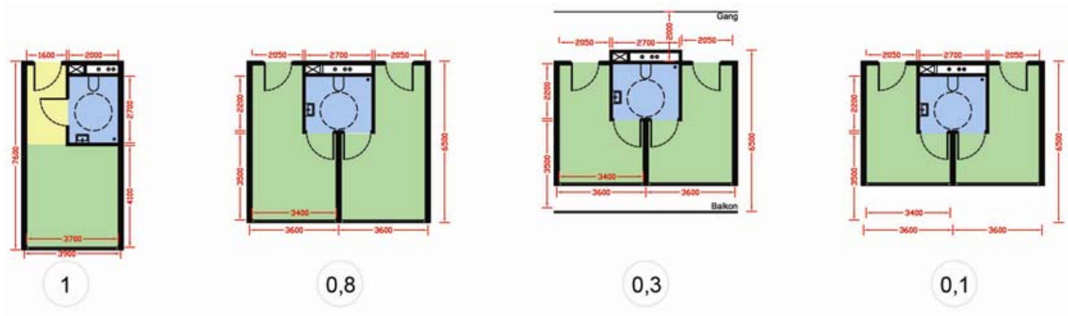

Figure 2: A grading of spatial solutions in terms of functionality

After grading is finalized for all aspects, the next step was to prioritize the relative importance of these aspects per scenario which was a starting point for knowledge modeling.

4 KNOWLEDGE MODELING

The systematization and the grading scheme are only a starting point for knowledge modeling. At this stage only information is provided, which cannot be used in a meaningful way, since at the level of systematization and grading there are no rules to apply that information. In other words, the interrelationship between the aspects is not yet modeled, which makes the information at hand difficult to interpret and apply in a knowledge form. Main purpose of this work was to model the knowledge which would be able to represent and capture expert's knowledge on the subject of transformation value. With such a model it would be possible for Bouwcollege to reuse the knowledge and apply it for evaluation of all houses for the elderly (more than 1000 buildings).

In general, knowledge can be characterized either as explicit or tacit. Explicit knowledge can be easily represented and applied due to its precise an unambiguous nature. It is mostly represented in building standards, regulations and guidelines. On the other hand, tacit knowledge, first introduced by Polanyi (1958), is much more difficult to represent, capture and reuse since it is generally fuzzy, ambiguous and imprecise. It is therefore rather difficult to express tacit knowledge since it is embedded in personal experience which involves subtle aspects such as personal beliefs, views and value system. It is a knowledge of experts regarding specific domain. Modeling tacit knowledge is a time consuming activity and knowledge models can be either *data* or *expert* driven. In first case, data driven knowledge models rely on large amount of data where some data mining techniques are applied for knowledge discovery and elicitation. Expert driven knowledge relies on one person's/group of experts knowledge on a particular subject (Durmisevic and Durmisevic, 2006). This paper deals with the later one, expert driven knowledge modeling, including both explicit and tacit knowledge.

Having systematized all aspects that are related to transformation capacity it was necessary to establish the relevant importance of all aspects. This was done using Analytical Hierarchy Process (Saaty and Alexander, 1981; Saaty and Vargas, 1982). The AHP method is a technique to compute the priority vector, ranking the relative importance of factors being compared. In the AHP computations expert knowledge plays the essential role. With AHP the model weights are determined. Based on these weights the structure of the knowledge model is established in a form of fuzzy-neural tree structure.

A fuzzy-neural tree is composed of terminal nodes, and weights of connection links between two nodes. Each terminal node is labelled with an element from the terminal set $T=\{x_1,x_2,\ldots,x_n\}$ where x_i is the *i-th* component of the external input vector $\boldsymbol{x}$**.** The input $\boldsymbol{x}$ is connected to a node via a radial basis function and provide an output for this node which is given by

$$f(x) = w_j \, \phi(\| x - c_j \|)$$

where φ *(.)* is the basis function, c_j is the centre of the basis function; w_j is the weight connecting the output of the basis function to the a terminal node in the form of an external input. c_j determined as a component of a priority vector and equal to w_j. Among several radial-basis functions, the Gaussian function

$$\phi(r) = \exp(-\frac{r^2}{2\sigma^2})$$

is of particular interest and used in this research due to its relevance to fuzzy-logic. Above, σ is the width of the basis function and it is used to measure the uncertainty associated with the node inputs designated as external input vector ***x***. For the model there can be as many basis functions as needed. The centres of the basis functions are the same as the terminal node inputs. Therefore for these input the radial basis function output is 1 and this is multiplied by the associated weight.

Neural networks can represent a broad class of feed-forward networks with or without layered structure. The tree structure involved in this work is a layered one and it allows for easy exchange of substructures by standard sub-tree variation operators without affecting the building blocks. Input from any sublevel to any upper level is possible. Connection between the nodes at the same level is also allowed. However, feedback from any upper level to sublevel is not allowed. By means of this basic configuration, the levels are clearly defined in a structure of any complexity (Ciftcioglu and Sariyildiz, 2006). *Figure 3* shows a configuration of the fuzzy-neural tree involved in this research.

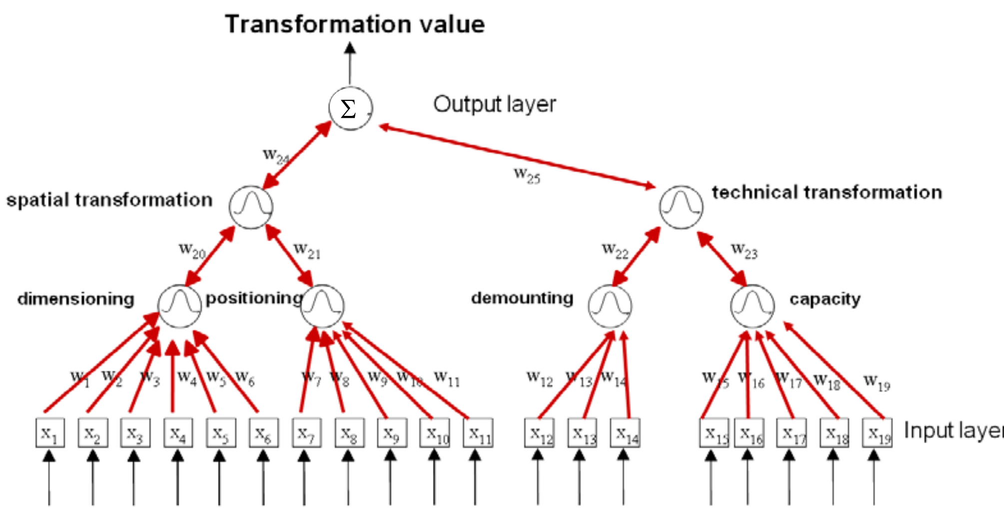

Figure 3: A schematic representation of a fuzzy-neural tree knowledge model

The lowest level has 19 nodes. The immediate upper level has 4 nodes, which is followed by a layer with two nodes. Finally, at the highest level there is one node which provides a final transformation value. The lowest level is a particular level since all the nodes have only a single input in this isolated configuration. The aspects listed in *table 1* are the inputs of the knowledge model, in *figure 3* represented as X_1 to X_n. The weights W_1 to W_n represent the factors of relative importance that were earlier established by the Analytical Hierarchy Process.

5 RESULTS

Since weights per scenario differ, this results into four knowledge models where each model corresponds to one of the scenario's. In other words, the inputs for a particular building remain the same for each scenario but the weights changed which resulted in four knowledge models. The interpretation of the results is in the following form (*table 2*):

Table 2: The output values obtained by knowledge models and the related interpretations

output values	**interpretation**
0.1-0.3	transformation potential is very low; the transformation of the building is not realistic due to a deficit of spatial and technical capacity;
0.3-0.5	transformation of a building is moderate with a high level of difficulty;
0.5-0.7	a building has a transformation potential with a small level of difficulty;
0.7-0.9	a building has a very high transformation potential (very few adaptations are necessary/ none or very low difficulty level);

The knowledge model software has been tested successfully on several case studies and is currently used by Bouwcollege to evaluate the remaining buildings. The main advantage of having such knowledge models is time efficiency in comparison with comprehensive studies and months of elaboration needed only for one building to come to a conclusion regarding transformation potential. *Figure 4* show the results obtained by knowledge models for Om en Bij, indicating that a first scenario (transforming into a nursing home, 6-10 persons per group) would be the best fitting option for this building.

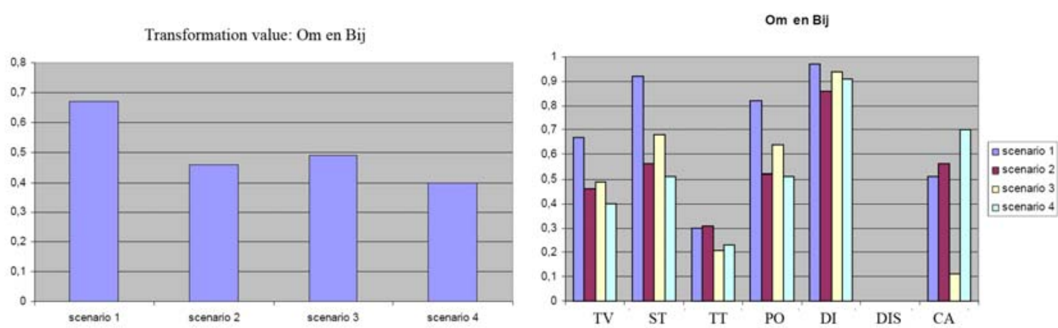

Figure 4: Transformation value for four scenarios (left) and more specific results (right - for explanation of abbreviations see *table 1*)

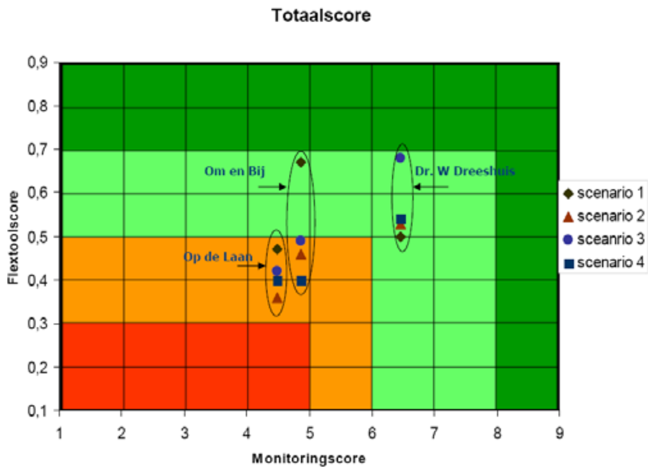

Figure 5: The monitoring results combined with the results from knowledge models (Nauta, 2007)

Comparing the results of the monitoring study and knowledge model (figure 5) indicates that a building Om en Bij, which had a low score in the monitoring, due to its technical and spatial organization could be transformed into a nursing home according to new use requirements. The results obtained by knowledge models show that a building has a transformation potential with a small level of difficulty.

6 CONCLUSIONS

The fuzzy-neural tree structures is especially suitable for tacit knowledge modeling. Firstly, considering the linguistic nature of the architectural data, fuzzy logic techniques are invoked. Secondly, knowledge is represented in a form of neural tree where the processing nodes are crucial for model functioning. In contrast to data driven knowledge models this is an expert driven knowledge model, which mainly captures the tacit expert's knowledge on this particular subject. Such a model is supposed to be generic and robust enough for buildings evaluations in the domain of concern. The methodology explained in this paper shows a way to tacit knowledge modeling.

7 REFERENCES

Bouwcollege 2003. *Ombouwen van verzorgingsplaatsen.* Netherlands Board for Healthcare Institutions, Utrecht, 2003

Bouwcollege 2004. *AWBZ-voorzieningen: Bouwmaatstaven voor nieuwbouw*. Netherlands Board for Healthcare Institutions, Report number 0.114, Utrecht, 2004

Bouwcollege 2005. *Monitoring the building quality of nursing homes and houses for the elderly 2005* (Gebouwkwaliteit in de Verpleging & Verzorging 2005). Netherlands Board for Healthcare Institutions, rapportnummer 587 en 587A

CBS - Centraal Bureau voor de Statistiek 2003. *Het Jaar in Cijfers: 2003*. Drukkerij de Brink BV, Leiden, pp. 18-19

Ciftcioglu Ö and Sariyildiz, I. S. 2006. Knowledge model for knowledge management in the construction industry. Proc. *Joint International Conference on Construction Culture, Innovation, and Management (CCIM)*, 26-29 November 2006, Dubai, United Arabian Emirates.

Durmisevic, E. 2006. Transformable building structures: Design for disassembly as a way to introduce sustainable engineering to building design and construction. PhD thesis, Delft

Durmisevic, S. and Durmisevic, E. 2006. A knowledge model for assessment of transformation capacity with respect to spatial flexibility. *The joint international conference on construction culture, innovation and management: Sustainable development through culture and innovation*, 26-29 November 2006, Dubai, United Arab Emirates

Nauta, J. 2007. Presentation for the Meavita Woonzorg, 2007, The Netherlands

Polanyi, M. 1958. *Personal Knowledge: Towards a Post-Critical Philosophy*. Chicago University Press, Chicago

Schunselaar, T. 2006. *Flexibility in the care*. Graduation thesis, Hanzehogeschool Groningen, Academie van Architectuur, Bouwkunde en Civiele techniek, Utrecht, juni 2006

Saaty, T. L. and Alexander, J. M. 1981. Thinking with models: Mathematical models in the physical, biological and social sciences, Pergamon Press

Saaty, T. L. and Vargas, L. G. 1982. The logic of priorities: Applications in business, energy, health and transportation, Kluwer-Nijhoff Publishing

Splitting and managing the solar spectrum for energy efficiency and daylighting

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ABSTRACT: This paper analyses the possibilities and benefits of splitting the solar spectrum for natural illumination and heating water applications in buildings. A design concept for a solar spectrum splitting device is presented. It considers the use of a dichroic cold-mirror to separate the infrared from the visible light. The device is attached to a low-cost solar collector that can be integrated into a building façade or roof. An experiment to test the efficiency of the system is carried out. As a result, "cool" visible light carrying almost no heat can be transported by fiber-optic cables to increase natural illumination in core areas of buildings, while the infrared is used to heat water. Lighting efficiency and water heating efficiency are estimated.

1 INTODUCTION

Energy consumption in buildings accounts for almost 40% of the total energy produced in Europe. Despite innovations and the development of more energy-efficient appliances and building systems, energy demand continues to rise due to the fact that there are more buildings being constructed and higher comfort levels are required by occupants. As highlighted by Osbourn (1997, pp.4), today "a modern building is expected to be a life-support machine". In this context, the efficient use of solar radiation becomes a fundamental issue in the design of sustainable and low-energy buildings.

The energy impact of solar radiation in buildings is well investigated in the literature. Lighting management with artificial lighting dimming as a function of daylighting can result in lighting energy savings from 20% to 70%, depending on several factors such as the building design, positioning and local climate conditions. Overall building energy consumption can be reduced by10% to 30% if daylighting is used strategically. One of the main problems with achieving this goal is that the heat from the solar radiation needs to be extracted before it enters the building, so that additional savings can result from reducing air conditioning loads. In hot climates solar heat gain can account for over 50% of the total building envelope cooling load (Krarti et al 2005, Bodart & Herde 2002, Perez-Lombard et al. 2007).

In a modern economic perspective one can think of sunlight as a free service provided by nature. Even on a cloudy day the available light intensity outside a building envelope is enough to illuminate almost every indoor task. But to use the whole potential of solar radiation for building services applications one has to consider the separation of the solar spectrum into its basic components, visible light (VIS), infrared (IR) and ultraviolet (UV). If done properly, this approach can result in several benefits. For example, visible light can be used for natural illumination while the IR part of the spectrum can be redirected for other applications.

This paper analyses the possibilities and benefits of splitting the solar spectrum for natural illumination and heating water applications in buildings. A design concept for a solar spectrum splitting device and a low-cost solar collector are presented. Lighting efficiency and water heating efficiency are estimated.

2 SOLAR RADIATION AND DAYLIGHTING IN BUILDINGS

2.1 *Solar radiation and building services*

The solar irradiance on a perpendicular plane outside the Earth atmosphere is calculated as 1353 W/m2. This value is known as the solar constant. On the top of the atmosphere around 48% of solar radiation is in the visible range (380nm to 780nm), 6.4% is ultraviolet irradiance (<380nm), and 45.6% is infrared radiation (above 780nm). In power terms this corresponds to 660 W/m2 related to the visible range, 92.6 W/m2 to ultraviolet, and 614.4 W/m2 corresponds to infrared irradiance. On the planet surface the intensity of solar irradiance will vary greatly due to losses in the atmosphere (Eicker 2003, pp.16).

The major goal of solar radiation management inside a building is to use sunlight to its fullest, separating the spectrum (visible light, ultra-violet and infrared), controlling and directing it according to different building systems needs. Table 1 presents some possible applications for the solar spectrum components in building services applications. Note that the solar components "to avoid" for each application is also highlighted.

Table 1. Applications for solar radiation in building services.

Application	Part solar spectrum needed	Part solar spectrum to avoid
Natural illumination	Visible light (VIS)	IR
Space heating	Infrared (IR)	--
Hot water	IR	--
Photovoltaic (PV) - (generate electricity)	VIS	IR
Thermophotovoltaic (TPV) - (generate electricity)	IR	--
Organic Photovoltaic (OPV) – (generate electricity)	Full spectrum	--
Air purification	Ultraviolet (UV)	--
Water purification	Ultraviolet (+IR)	--
Natural ventilation (stack-effect)	IR	--

2.2 *Benefits of daylighting*

When thinking about solar radiation one automatically thinks about natural lighting. Daylighting is the complete design process and application of natural light to its fullest inside buildings (Karlen & Benya 2004, p.31). If it is done properly it can create interesting dynamic interiors, support human health and activities, improve work and learning performance, reduce environmental impact, and reduce energy demand. If done improperly, it causes discomfort glare and demands excessive energy to extract the generated heat (Leslie 2002, p.381, Fontoynont 2002).

Beyond the impact on energy saving and costs reduction, researchers have also found that natural light can provide a healthier indoor environment. Recent research shows that lighting has a more profound implication on human health and well-being that was once suspected (Berson 2003, Webb 2006). Pauley (2004) argues that natural light is the best to balance the circadian clock and also that indoor lighting should employ lights with wavelengths shifted toward the yellow and orange wavelengths. Olders (2003) report on the positive impact of daylighting on the treatment of depression and seasonal affect disorders (SAD).

2.3 *Solar spectrum splitting technologies and materials*

Imenes & Mills (2004) present a very comprehensive review of the literature on spectral beam splitting technologies for solar concentrating systems. Although the main focus of their review highlights the applications for photovoltaic and thermophotovoltaic energy conversion, most of the principles can also be applied to daylighting systems. The authors classify current beam splitting methods in the following categories: (1) transmissive and reflective methods; (2) refractive and absorptive filtering methods; (3) luminescent filtering methods; (4) holographic filtering methods.

Dichroic materials, cold mirrors and hot mirrors can also be applied to separate the solar spectrum. Dichroic materials are manufactured on a glass or plastic base on which alternate layers of transparent materials are laid. The amount and values of the wavelength transmitted or reflected depend on the thickness and refractive index of each layer. It reflects visible light and transmits the IR, being also referred as a “cold mirror”. Changing the order of the layers reflects the IR and transmits the visible light. In this configuration it is referred as a “hot mirror”. Magnesium fluoride/zinc sulphide and tantala/silica oxides are some examples of dichroic layers. (Elmualim et al. 1999, pp.255). Dye et al (2003) report a full-spectrum solar concentrator system that also applies a dichroic cold mirror to separate the infrared from this visible light. In this system the IR is directed towards a thermophotovoltaic (TPV) cell array to generate electricity, while the visible light is used for natural illumination or photobioreactors.

3 SYSTEM DESIGN AND PROTOTYPING

3.1 *Optical system configuration and dichroic cold mirror device*

To separate the infrared from the visible light we used a dichroic cold mirror made of borosilicate (LEBG) float glass, 50x50mm and 3mm thickness. Operating at an angle of 45 degrees it reflects over 90% of visible light (425-650nm) while around 85% of the infrared (800-1200nm) is transmitted through.

The cold mirror was mounted at an angle of 45 degrees inside a device specially designed for it. The device is attached to the solar collector. Figure 1 illustrates how the system is expected to work. A flux of collimated sunlight, concentrated by the solar collector, is directed towards the cold mirror. Visible light (VIS) is reflected down while the infrared (IR) passes through. Collimation is a fundamental requirement for the efficient separation of the solar spectrum using a dichroic cold mirror. This means that incoming rays must be parallel so that sunlight intensity is maximized. If most of the incoming light flux is not collimated the infrared and visible light will not be separated.

A photometer (light meter) is connected to the visible light exit, measuring the light level (illuminance, lx) output of the system. The projected area of the cold mirror (50x50mm, positioned at 45 degrees) over the visible light exit is 50x36mm. The same projected area covers the infrared exit. It is important to note that the cold mirror projected area of 50x36mm will de used later on in this paper to calculate the lighting efficiency of the system (luminous intensity and illuminance).

At the infrared exit an aluminum container with 500ml of water is kept isolated inside a larger container. The internal and external walls of the larger container are covered with thermal insulation. An infrared reflective coating covering the internal walls of the container helps to keep the infrared trapped inside. The aluminum container is painted in black. A small window on the side of the larger container can be opened to take measurements of the water temperature using an infrared thermometer (Fig.1).

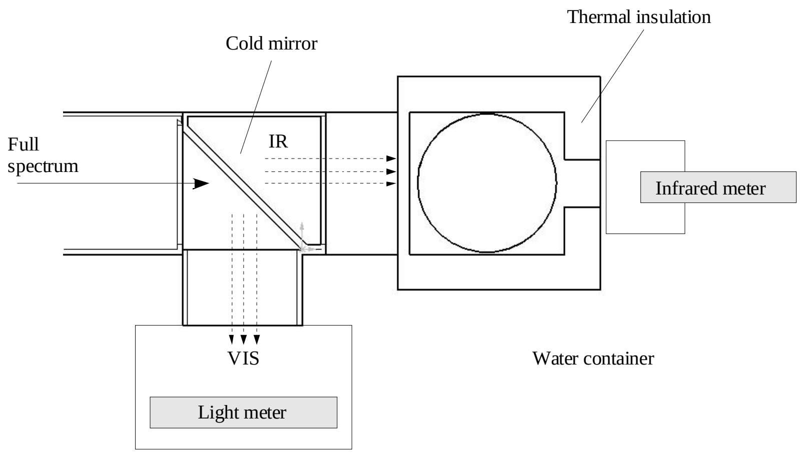


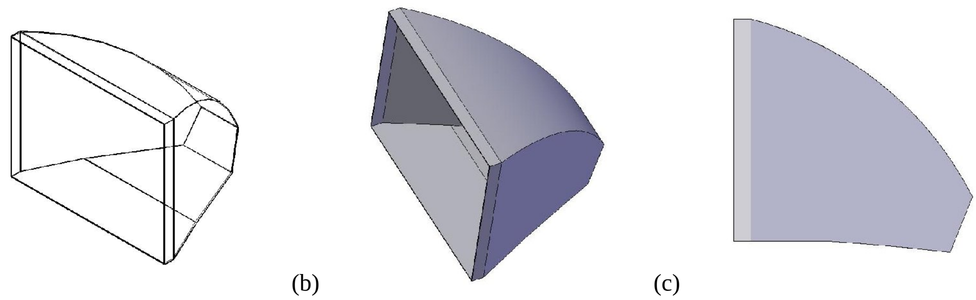
Figure 1. Schematic representation of the device used to separate the infrared (IR) and the visible light (VIS).

3.2 *Design and mock-up prototyping of the solar collector*

Our intention for this experiment was to develop a low-cost passive (non-tracking) solar collector, rather than a high cost system tracking system. CAD software was applied to design the system and preliminary virtual simulations were done using OptiCAD, an optic-design specialist software. Using ray-tracing analysis tools it was possible to optimize the system and define the best acceptance angle for solar incidence.

The final solar collector mock-up was optimized for the experiment location (London, UK: 51 38' N; 07' W) and has an acceptance angle of 50 degrees. Positioned at an angle of 45 degrees and facing south it achieves its highest efficiency range from 12:00h to 13:30h. It has a frontal area of 440x200mm which represents around 1/11 square meter. In other words, an array of eleven solar collectors (440x200mm) occupies an area of one square meter.

A fundamental requirement for the system was to maximize the reflectivity of the visible light and the infrared inside the solar collector. This is an essential issue in a system that intends to use both visible light and infrared. For this reason it was important to choose reflective materials, coatings and optical components that worked well for both visible light and infrared. We used Mylar to cover the internal surfaces of the solar collector. This material reflects both visible light and infrared with an efficiency of 90-95%. Figure 2 shows perspectives and side views of CAD drawings of the proposed solar collector.



(a) (b) (c)

Figure 2. CAD drawings of the solar collector. Perspective views (a) and (b). Side view (c).

4 EXPERIMENTS AND RESULTS

4.1 *Experiment set-up*

Two experiments were realized in London (51 38' N; 07' W), both in late April 2007. The mock-up prototype of the designed solar collector was installed indoors, above a double-glazing window facing south. The area of the collector received direct sunlight from around 10:30 in the morning to 16:30 in the afternoon. In the first experiment the collector was positioned at an angle of 30 degrees in relation with the ground floor. For the second experiment the angle was increased to 45 degrees so that the frontal area of the collector was facing the sun during a longer period. Table 2 presents a summary of the conditions for each experiment.

Table 2. Solar collector set-up, weather conditions and sky illuminance for experiments 1 and 2.

Experiment	Solar collector set-up		Weather conditions	Sky Illuminance (lx)		Hours
	Orientation	Positioning		Max.	Min.	
Experiment 1 (25.04.2007)	South	30 degrees	Variable, sun spells Partial cloud, rain	70000	1000	3 hours
Experiment 2 (30.04.2007)	South	45 degrees	Bright sunny, No clouds	>100000	30000	5 hours

4.2 *Data gathering and results*

Measurements of visible light output and temperature variation in the 500ml water container were taken every 10 minutes. Visible light was measured using two photometers (Extech Light Meter EA31 and Extech Light Meter EA33). An infrared thermometer (Extech 42529) was used to measure variations in the water temperature.

Figure 3 and Figure 4 plots the results from the first experiment. Figure 5 and Figure 6 plots the results from the second experiment. Two major variables were responsible for the great differences between the results. One is the positioning angle of the solar collector (30 degrees in the first experiment and 45 degrees in the second). The other variable was the weather conditions. Cloudy weather with few sunny spells was predominant during the first day of experiment, while a sunny day with blue sky and no clouds was a gift for the second experiment.

The light level output of the system is presented as “system lux” in Figure 3, for experiment 1, and Figure 5, for experiment 2. The “sky lux” term refers to the light level values of the sky illuminance, measured by positioning the photometer in a horizontal position under direct sunlight.

Temperature variations of the 500ml water container are presented in Figure 4, for experiment 1, and Figure 6, for experiment 2. The temperature of the water container that receives infrared radiation from the solar collector is noted in the legend of Figure 4 and Figure 6 as “Temp.C1”, marked with a square in the graph. “Temp.C1” is the water container presented firstly in Figure 1. “Temp.C2” and “Temp.C3” refers to two other 500ml water containers that were used as reference. The container “Temp.C2” was positioned under direct sunlight, while the container “Temp.C3” was kept in the shade at room temperature. The three water containers start with the same temperature, 21 degrees Celsius, in both experiments.

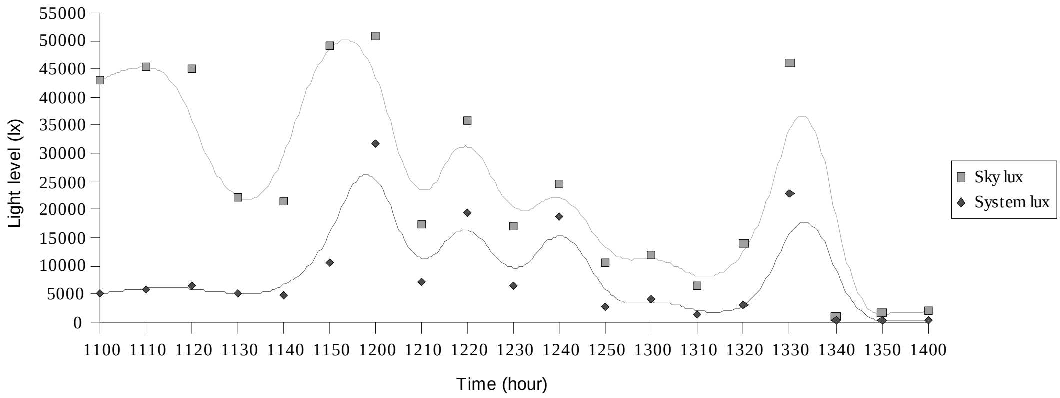


Figure 3. Light level data collected from the first experiment.

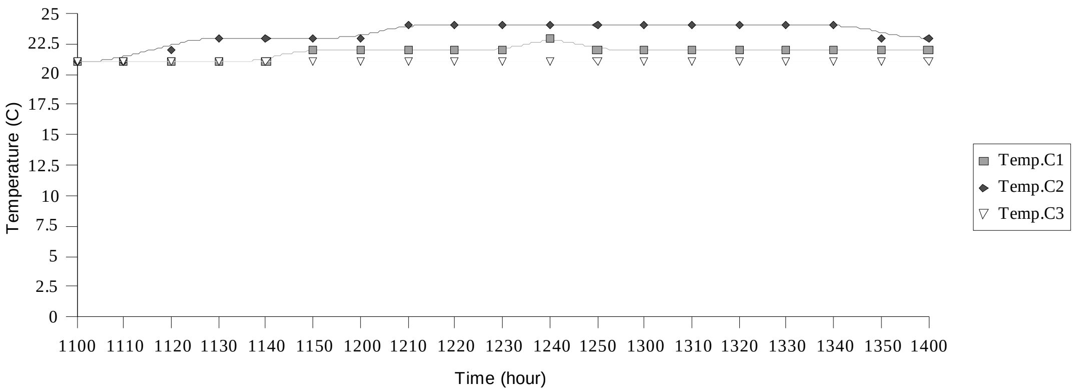


Figure 4. Temperature data collected from the first experiment.

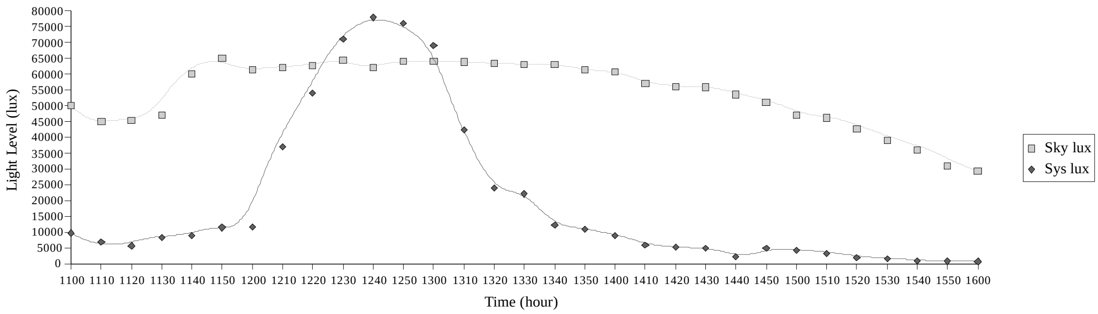


Figure 5. Light level data collected from the second experiment.

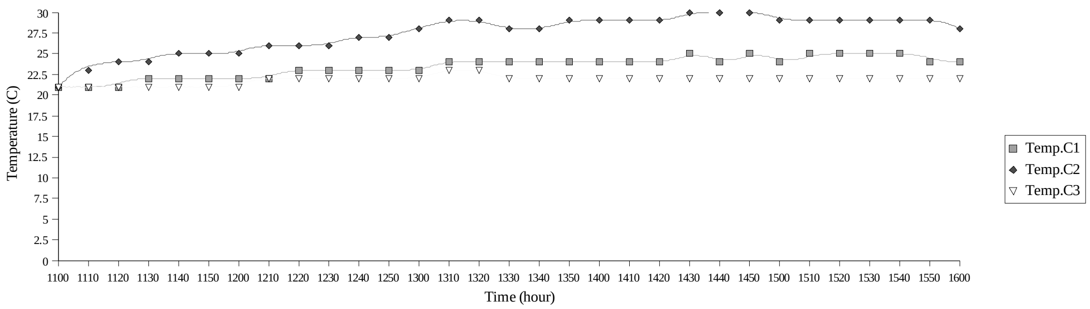


Figure 6. Temperature data collected from the second experiment.

4.3 *Estimating lighting efficiency*

Lighting efficiency is analyzed here in terms of the luminous output of the system considering the data collected from the two experiments. Calculations result from an estimation of the performance of a system with the same configuration but with a frontal area of one square meter.

Table 3 and Table 4 present the estimated performance for a system with a frontal area of one square meter. Data is extracted from Figure 3 and Figure 5 and rearranged in time periods of 30 minutes. This procedure helps to estimate the average performance of the system at different periods of time and under different weather conditions. The columns under the term "system efficiency" present the average value of the luminous flux (in lumens). To calculate the transmission efficiency we estimate that all lumens output is concentrated directly into a bundle of acrylic (PMMA) fiber optical cables (core diameter of 1mm, attenuation 0.21 dB/m). Light transmission efficiency through the fiber optical cables are estimated to be 75% after 5m, 40% after 10m, and only 10% after 20m. Values are approximated.

Considering the values presented in Table 4 we calculate that, at its peak efficiency (from 12:30 to 13:00), the system is capable to illuminate an area of 10m² with an illuminance level of 112lx (after 5m), 60lx (after 10m) and 15lx (after 20m).

Table 3. Luminous flux out put and estimation of the transmission efficiency for experiment 1.

Time	System efficiency (Exit output)	Light transmission efficiency for 1mm PMMA fiber optical cable		
		After 5m (75%)	After 10m (40%)	After 20m (10%)
	Lumens	Lumens	Lumens	Lumens
1100 – 1130	114	85.5	45.6	11.4
1130 – 1200	268	201	107.2	26.8
1200 – 1230	332	249	133	33.2
1230 – 1300	163	122.3	65.2	16.3
1300 – 1330	159	119.3	63.6	15.9
1330 – 1400	123	92.2	49.2	12.3

Table 4. Luminous flux output and estimation of the light transmission efficiency for experiment 2.

Time	System efficiency (Exit output)	Light transmission efficiency for 1mm PMMA fiber optical cable		
		After 5m (75%)	After 10m (40%)	After 20m (10%)
	Lumens	Lumens	Lumens	Lumens
1100 – 1130	156	117	62.4	15.6
1130 – 1200	206	154.5	82.4	20.6
1200 – 1230	887	665.3	354.8	88.7
1230 – 1300	1502	1126.5	601	150.2
1300 – 1330	804	603	321.6	80.4
1330 – 1400	278	208.5	111.2	27.8
1400 – 1430	127	95.3	50.8	12.7
1430 – 1500	83	62.2	33.2	8.3
1500 – 1530	57	42.8	22.8	5.7
1530 – 1600	20	15	8	2

4.4 *Estimating water heating efficiency*

The system water heating efficiency was measured considering the difference between the temperature of the water in the container that received direct infrared from the system (Temp.C1, from Figures 4 and 6), and the temperature of the reference water container that was kept isolated at room temperature (Temp.C3, from Figures 4 and 6). Table 5 shows the average and the peak temperature differences measured in the experiments.

Although only a small change in temperature was measured, it is important to note that the system sustained the temperature difference for more than two hours in the first experiment (that lasted only 3 hours) and for four and a half hours in the second experiment (that lasted 5 hours).

We estimate that a 1m² array of solar collectors (with the same configuration as the one described in this paper, and under the same weather conditions) would be able to sustain an increase of up to 3 degrees Celsius in 5 litre of water during at least one and half hours. To increase 3 degree Celsius in the temperature of 50 litre of water would require a solar collector array with an area of 10m².

Table 5. Water heating efficiency for experiments 1 and 2.

Time	Experiment 1 Temperature difference (Celsius)		Experiment 2 Temperature difference (Celsius)	
	Average	Peak	Average	Peak
1100 – 1130	-	-	-	1 (at 11:30)
1130 – 1200	1	1 (at 11:50)	1	-
1200 – 1230	1	-	1	-
1230 – 1300	1	2 (at 12:40)	1	-
1300 – 1330	1	-	1	2 (at 13:30)
1330 – 1400	1	-	2	-
1400 – 1430	-	-	2	3 (at 14:30)
1430 – 1500	-	-	3	-
1500 – 1530	-	-	3	-
1530 – 1600	-	-	3	-

5 DISCUSSION AND CONCLUSION

Solar radiation can result in a more positive contribution to buildings systems and services if visible light and infrared are separated. The system presented in this paper is capable to deliver up to 1120lm through 5m of fiber optical cables. Although this is considered a low luminous flux, it is still able to illuminate an area of 10m² with 112lx (after 5m). We estimate that an array of solar collectors with 3m² to 5m² will be able to deliver up to 560lx of natural light (with no infrared) to an area of 10m² located 5m deep into the building. This is enough for almost all tasks realized in educational and office buildings, for example (CIBSE, 2002).

The strategy for the solar collector was to design a low-cost passive (non-tracking) system that could be easily integrated into a buildings façade or roof top. Our intention for this experiment was to develop a low-cost (and low-efficiency) system, rather than a high efficiency-high cost system. The solar collector acceptance angle can be optimized for different site locations considering the positioning of the building on the Earth surface (longitude and latitude). It also can be optimized according to the façade where it is positioned (facing south, west, east or north).

Some small improvements in the system could increase its performance significantly. Using a better cold mirror (with infrared transmission of up to 2500nm) it may be possible to increase the water temperature. We expect to at least double the efficiency of the system while keeping costs low.

Acknowledgments

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REFERENCES

CIBSE, 2002. *Code for Lighting*. Oxford: Butterworth-Heinemann.

Berson, D.M. 2003. Strange vision: ganglion cells as circadian photoreceptors. *Trends in Neurosciences* 26(6): 314-320.

Bodart, M. & De Herde, A. 2002. Global energy savings in offices building by the use of daylighting. *Energy and Buildings* 34: 421-429.

Dye, D. et al. 2003. Optical design of an infrared non-imaging device for full-spectrum solar energy systems. *Proceedings of International Solar Energy Conference, Hawaii, USA, 15-18 March 2003*.

Eicker, U. 2003. *Solar Technologies for Buildings.* Chichester, England: John Wiley & Sons.

Elmualim, A.A. 1999. Evaluation of dichroic material for enhancing light pipe/natural ventilation and daylighting in an integral system. *Applied Energy* 62: 253-266.

Fontoynont, M. 2002. Perceived performance of daylighting systems: lighting efficacy and agreeableness. *Solar Energy* 73(2): 83-94.

Imenes, A.G. & Milles, D.R. 2004. Spectral beam splitting technology for increased conversion efficiency in solar concentrating systems: a review. *Solar Energy Materials & Solar Cells* 84:19-69.

Karlen, M. & Benya, J. 2004. *Lighting Design Basics.* Hoboken, New Jersey: John Wiley & Sons.

Krarti, M. et al. 2005. A simplifies method to estimate energy savings of artificial lighting use from daylighting. *Building and Environment* 40: 747-754.

Leslie, R.P. 2003. Capturing the daylighting dividend in buildings: why and how? *Building and Environment* 38: 381-385.

Olders, H. 2003. Average sunrise time predicts depression prevalence. *Journal of Psychosomatic* 55: 99-105.

Osbourn, D.1997. *Introduction to Building*. Essex, England: Addison Wesley Longman.

Pauley, S.M. 2004. Lighting for the human circadian clock: recent research indicates that lighting has become a public health issue. *Medical Hypotheses* 63: 588-596.

Perez-Lombard, L. et al. 2007. A review on buildings energy consumption information. *Energy and Buildings* (article in press).

Webb, A.R. 2006. Considerations for lighting in the built environment: non-visual effects of light. *Energy and Buildings* 38: 721-727.

A sustainable technical system for ventilated façades

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ABSTRACT: This paper studies industrial systems of facades ventilated from market products, detachable and recyclables. Also it assessments the probable durability of the components of the facade, it tracks his service life and it determines the environmental impact that it causes due to the energy and CO2 produced in the obtaining and manufacture of the materials that compose it.

1. CONSTRUCTION TECHNIQUES FOR THE FAÇADES OF RESIDENTIAL BUILDINGS

Façades of residential buildings in Spain have been built usually out of brick. The most commonly used construction technique (from inner to outer) has consisted of: plaster siding, a 7.5 cm partition wall, an air chamber with neither ventilation nor drainage, thermal insulation of variable thickness and an exterior wall made of brick, either 11.5 or 14 cm, with or without exterior cladding. Carefully implemented, this construction technique complies fairly well with the Technical Building Code's current basic requirements for façades: (1) safety in the event of fire, thermal and acoustical insulation, resistance and stability against wind loads, and impermeability (waterproofness).

The appearance and fast growth of the construction model known as "rain screen" (2), or "ventilated façade," has come about because of an inability to insulate properly the edge of the framework, generating thermal bridges; compatibility problems resulting from the wide dimensional tolerances of the concrete structures; and above all, the architects' desire to experiment with new products and materials in the building of façades. This new construction technique (technique 1) consists (from inner to outer) of: one or two sheets of plasterboard attached to flashings, an 11.5 or 14 cm brick wall, thermal insulation of variable thickness, a ventilated and drained chamber, and a cladding system of rigid plates with specific fastenings. The cladding system is usually attached to the wall and to the edges of the framework.

At present, various cladding systems have been developed and optimised for this type of façade; in particular, asbestos cement, thermo-hardened resin or porcelainised stoneware plates. This construction technique complies well with some of the demands imposed upon the façade: thermal and acoustical insulation and impermeability; but a thorough analysis is required with regard to the problem of safety in the event of fire, because of the risk of a fire spreading through the chamber to the entire façade (3).

One cannot disregard wind activity either; suction and/or pressures, usually weak, that may act on the plates as a result of the compartmentalization of the air chamber, or on the inner masonry wall (4). Despite these inconveniences, this type of construction technique is gaining ground on façades for residential, administrative, hospital, and school buildings.

Lately, a further step has been taken. In some projects, mainly in hotels and dwellings, the brick wall has been substituted by a sandwich made of steel plate sections that act as resistant elements, acoustical and thermal insulation, one or more sheets of plasterboard as cladding for the inner side, and a special asbestos cement plate as cladding for the side that is exposed to the elements. Sometimes the asbestos cement side is clad with complementary thermal insulation to minimise the thermal bridges caused by steel plate vertical girders or by the edges of the framework. This construction technique (technique 2) is complemented, similarly to the prior technique, with a system of exterior cladding made of rigid plates with specific fastenings. The tremendous popularity of this technique is a result both of the elimination of humid conditions in the façade's building stage, and of the search for more industrialised building processes that generate less waste during construction, waste that is lighter and not as thick as that generated by previously described techniques.

Nonetheless, the substitution of one type of façade construction technique for another cannot be automatic, inasmuch as the brick wall unquestionably helps to achieve technical benefits that could not otherwise be easily accomplished. We refer in particular to acoustical insulation, impermeability to wind, safety in the event of fire, and even resistance and stability of the cladding system.

First and foremost, the façade must be solid and durable; must create comfort, primarily thermal, acoustical and with reference to light, in inner spaces; must be waterproof; must be safe in case of fire; and must be energy efficient.

This paper analyses various ventilated façade techniques that are being built in Spain at present, with similar technical benefits: construction techniques 1 and 2, with different types of cladding systems: (A) porcelainised stoneware plates, (B) thermo-hardened resin plates, and (C) asbestos cement plates, comparing different parameters: weight per square meter – energy consumption of materials – CO_2 production.

2. CONSTRUCTION FEATURES AND TECHNICAL BENEFITS OF THE DIFFERENT TYPES OF FAÇADE ANALYSED

2.1 *Construction technique 1.*

Composition (from inner to outer): two sheets (13 mm) of plasterboard on sections of galvanised steel, 14 cm perforated brick wall (1500 k/m³), 1 cm plaster mortar, 50 mm rockwool panel (50 k/m³), ventilated and drained air chamber.

Technical features:
Thermal transmittance: U = 0.59 W/m2 K
Global index of acoustical insulation: Ra > 46 dBA
EI > 120’

2.2 *Construction technique 2.*

Composition (from inner to outer): two sheets (13 mm) of plasterboard on sections of galvanised steel, 50 mm rockwool panel (50 K/m³), 22 mm asbestos cement plate, 30 mm rockwool plaster and mortar. In order to meet the resistance function, this technique incorporates a substructure of 100 x 50 x 1.5 cm tubular piping, at every 1200 mm vertically and 700 mm horizontally.

Technical features (5):
Thermal transmittance: U = 0.62 W/m2 K
Global index of acoustical insulation: Ra > 46 dBA
EI > 60’

2.3 *Cladding system A.*

Composition: 120 x 60 cm and 12 mm thick porcelainised stoneware plates. Anodised aluminium sections according to DITE 353 (6).

3.2 *Cladding system B.*

Composition: 10 mm thick thermo-hardened synthetic resin plates. Anodised aluminium sections according to DITE 240 (7).

3.3 *Cladding system C.*

Composition: 6 mm thick asbestos cement plates. Sections of folded galvanised steel according to DITE 403 (8).

3. RESULTS OBTAINED

Resulting values as to weight (K/m²), energy utilised (MJ/m²) and CO_2 production (K/m2) are recorded on the spreadsheet attached to this paper, obtained from ITEC's DB Table (9), for façade construction techniques 1 and 2, as well as for the three types of exterior cladding (A, B and C).

4. CONCLUSIONS

4.1 *Concerning construction techniques 1 and 2.*

- Construction technique 2 is lighter than technique 1 (0.584 KN/m² against 2.51 KN/m2). In buildings with a large number of stories, this feature allows a reduction in the amount of material needed for construction of the structure and foundation, which is a positive result because of a reduction in the level of CO_2 emitted during manufacture of these materials, as well as in the energy consumed in said processes.

- Construction technique 2 requires more energy per square meter than technique 1 for its manufacture (1032.40 MJ/m² against 694.65 Mj/m²). Moreover, construction technique 2 produces larger quantities of CO_2 in the manufacture of its materials than construction technique 1, (88.23 Kg CO_2/m² against 54.93 Kg CO_2/m²). One could evaluate for a particular building the influence on the final result of the reduction in materials for structure and foundation because of the lighter weight of construction technique 2. Another conclusion derived is that construction technique 2 should have a smaller thermal transmittance value so as to compensate during its useful life for the excess energy and CO_2 production that it has as opposed to construction technique 1. This conclusion, arising as it does from the sustainability approach, agrees with the thermal comfort approach, inasmuch as construction techniques with little thermal inertia, as is the case with construction technique 2, require more thermal insulation to compensate for their quick thermal response to outside weather changes.

4.2 Concerning the exterior cladding of plates.

- All three claddings present a similar surface weight (weight of cladding A = 0.274 KN/m²; weight of cladding B = 0.179 KN/m²; weight of cladding C = 0.199 KN/m²).

- The three claddings present considerable differences as to the energy required to manufacture the various materials of which they are composed (cladding A, of porcelainised stoneware plates, 1223.81 Mj/m²; cladding B, of thermo-hardened synthetic resin plates, 702.53 Mj/m²; cladding C, of asbestos cement plates, 303.62 Mj/m²). These differences particularly have to do with the material used in the manufacture of the metallic sections that comprise the substructure, thus, the use of a material requiring less energy would improve the cladding solution. An important point, unavailable to us, would be to ascertain the useful life of each cladding, which would allow an evaluation of the energy rate consumed for each year of useful life. The materials that comprise the chosen claddings allow closing of their respective cycles by means of recycling.

- Similarly, the three claddings present considerable differences regarding CO_2 emissions produced when manufacturing the various materials of which they are composed (cladding A, of porcelainised stoneware plates, 166.23 Kg CO_2 /m²; cladding B, of hardened synthetic resin plates, 84.18 Kg CO_2 /m²; cladding C, of asbestos cement plates, 29.02 Kg CO_2 /m²). These differences particularly have to do with the material used in the manufacture of the metallic sections that comprise the substructure, thus the use of a material that would emit less CO_2 during its manufacture would improve the cladding solution. An important point, unavailable to us, would be to ascertain the useful life of each cladding, which would allow an evaluation of the rate of CO_2 that has been emitted for each year of useful life.

4.3 Concerning the whole of the construction techniques for ventilated façades.

- Different combinations of construction techniques (1 and 2) and exterior claddings present big differences with regard to the energy required and CO_2 emitted in manufacture of the materials:

Construction technique 2 + cladding A: (2556.21 Mj/m2 and 255.16 Kg CO_2 /m2)

Construction technique 1 + cladding C: (998.27 Mj/m2 and 83.95 Kg CO_2 /m2).

These differences cannot be taken as definitive when selecting materials for the ventilated façade, but rather as a clear reference; as it has been said earlier, the cladding material's useful life is an important piece of information that depends on the environmental characteristics of the site where it is placed.

4.4 Final conclusions.

- Generalised adoption of industrialised construction techniques to build façades will imply larger energy consumption and CO_2 emissions that can only be compensated by a decrease in the amount of material for structure and foundation because of its lesser weight.

A possibly negative final impact with regard to the environment should be balanced by improvement of the thermal insulation for the techniques and with a larger useful life for these.

- Despite the larger energy consumption and CO_2 emission, industrialised and light construction techniques for façades permit a better use of the materials that integrate them when they are able to close the life cycle through recycling or even through reuse of the materials.

- It is possible that industrialised construction techniques for wood with simple fastenings may add a reduction in energy consumption and CO_2 emissions during manufacture to the better use and recycling of the materials.

Construct system **1**: Wall clay brick.	Gypsum plasterboard, 13 mm (x2).	20,54	162,26	9,66
	Vertical girder from Galvanized steel	1,88	75,2	7,33
	Wall of thickness closing supported 14 cm, of brick perforated of 29x14x7,5 cm, taken with mortar for industrialized masonry M 5 (5 N/mm2).	204,82	363,07	28,62
	Mortar continuous stucco of 1 cm (Portland cement with limestone proportion 1:4).	21,15	32,15	3,72
	Insulation rock wool 86 to 95 kg/m3 of 50 mm of thickness, placed with mechanical fixations.	2,79	61,97	5,6
	TOTAL	**251,18**	**694,65**	**54,93**

Construct system **2**: Light weight wall.	Gypsum plasterboard, 13 mm (x2).	20,54	162,26	9,66
	Stud of galvanized steel, wide post of 46 mm, placed each 40 cm and channel of 46 mm fixed mechanically.	2,78	111,2	10,84
	Structure galvanized steel profiles 100X50X2 + Horizontal reinforcement crosspiece of 50x50x2	7,54	301,6	29,41
	Insulation rock wool 86 to 95 kg/m3 of 50 mm of thickness, placed with mechanical fixations.	2,79	61,97	5,60
	Cement fibreboard, 12,5 mm	21,88	335,34	27,56
	Insulation rock wool 86 to 95 kg/m3 of 30 mm of thickness, placed with mechanical fixations.	2,92	60,03	5,16
	TOTAL	**58,45**	**1032,40**	**88,23**

Cladding of Stoneware **(A)**	Aluminum profile for anchorage to the plate.	0,83	169,90	25,02
	Aluminum Vertical profile	2,59	530,17	78,06
	Aluminum Horizontal profile	1,34	274,30	40,39
	PUR adhesive	0,05	2,23	0,33
	Plates Stoneware, thickness 12 mm.	22,68	247,21	23,13
	TOTAL	**27,49**	**1223,81**	**166,93**

Cladding of Synthetic Composite **(B)**	Aluminum profiles for vertical frame thickness to 1.8 mm width profile 40 mm.	1,29	264,06	38,88
	Aluminum Horizontal profile	1,06	216,98	31,95
	Square of galvanized steel regulation.	0,15	5,88	0,57
	Board of thickness 10 mm, reinforced synthetic resins with wood fibers.	15,4	215,6	12,78
	TOTAL	**17,90**	**702,53**	**84,18**

Cladding of Composite Cement Febreboard **(C)**	Vertical Profiles galvanized steel of 1.5 mm of thickness and length 6m, dimensions 29x50x40.	3,67	146,8	14,31
	Squares of fixation to the galvanized steel support, thickness 2.5 mm, dimensions 48x80x60 mm.	0,07	2,92	0,28
	Composite cement febreboard, espesor 9 mm.	16,2	153,9	14,42
	TOTAL	**19,94**	**303,62**	**29,02**

Summary of environemental impact of emissions and energy			Mass Kg/m2	Energy Mj/m2	Emissions KgCO2/m2
1	**A**	Construct system 1: Wall clay brick + Cladding of Stoneware	**278,67**	**1918,46**	**221,86**
	B	Construct system 1: Wall clay brick + Cladding of Synthetic Composite	**269,08**	**1397,17**	**139,12**
	C	Construct system 1: Wall clay brick + Cladding of Composite Cement Febreboard	**271,12**	**998,27**	**83,95**
2	**A**	Construct system 2: Light weight wall + Cladding of Stoneware	**85,93**	**2256,21**	**255,16**
	B	Construct system 2: Light weight wall + Cladding of Synthetic Composite	**76,34**	**1734,93**	**172,41**
	C	Construct system 2: Light weight wall + Cladding of Composite Cement Febreboard	**78,39**	**1336,02**	**117,25**

REFERENCES

1. Código Técnico de la Edificación. Ministerio de la Vivienda. (España 2006).
2. J.M. Anderson and J.R. Gill, Rainscreen cladding: a guide to design principles and practice. (Butterworths, London 1988).
3. Sara Colwell and Brian Martin, Fire performance of external thermal insulations for walls of multi-storey buildings. (Building Research Stablishment 2003).
4. D.R. Inculet and A.G. Davenport, Pressure-equalized rainscreens: A study in the frequency domain. (Journal of Wind Engineering and Industrial Aerodynamics 53. 1994)
5. Technical sheet W380 E, Aquapanel Outdoor.(Knauff, 2006).
6. Agreement nº 353 "Sistema de fachada ventilada Mecanofas Karrat S-7. (Instituto de Ciencias de la Construcción Eduardo Torroja).
7. Agreement nº240 "Cerramiento para fachadascon placas de material sintético termoendurecible TRESPA". (Instituto de Ciencias de la Construcción Eduardo Torroja).
8. Agreement nº 403 "Sistema de revestimiento de fachadas ventiladas con placas planas Naturvex TC". (Instituto de Ciencias de la Construcción Eduardo Torroja).
9. Metabase de la construcción (Institut de Tecnologia de la Construcció de Catalunya. ITEC).

Architectural beam of light
use of daylight pipes in climates of high latitude

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In a climate of high latitude the main inconvenience in relation to natural light in buildings is the capture of that light into deeper areas of the building. The standard system (large windows) has difficulties with overcast conditions because the light does not penetrate deep into the room. A solution to this problem has been designed by Serra in 1999 "Sun pipe". These devices are mirrored ducts designed to introduce sunlight into the deeper interior of buildings. The "Sun pipe" does not however work effectively in climates of high latitude because the light is often of a diffused nature in these climates. The geometry of the capture component in the proposed "light pipe" is an innovative solution for bringing daylight into deep areas within buildings in climates of high latitude, which it cannot reach by other means.
Key words: Diffused daylight, Capture of light, high latitude, Light pipe.

When is a building sustainable? A building is not sustainable in itself; what should be sustainable are the activities carried out in a building and a building should be flexible to allow it to adapt to these functions.

As the sun is the ultimate source of energy (or power), it should and has to be profited as extensively and efficiently as possible. Sunlight is one of the most beautiful and powerful elements available to architects. Unlike wood or steel its supply is free and boundless. Daylight provides building users with superior visual acuity, a sense of psychological well being, and dramatic energy savings. Naturally lit buildings help people to relate to daily and diurnal rhythms of light and darkness, providing awareness of the world outside and a sense of belonging in one's natural environment. Exposure to more natural light helps people to work more comfortably, safely, and effectively.

Recently advances in the area of solar technologies have opened up further opportunities to effectively utilize this completely renewable and sustainable energy source. This has allowed our species the opportunity to progress more in harmony with our planet without compromising our natural environment for future generations. The use of renewable energies in buildings contributes to the reduction of the primary energy demand (fossil fuels etc) irrespective of the contribution of passive solar energy. This helps reduce CO_2 emissions and minimize the associated impact on the environment. It also helps to reduce energy costs for the end user.

In this paper an advanced day lighting system 'light pipe' is presented to provide higher work plane luminance levels into deep areas within buildings in climates of high latitude, where daylight cannot reach by other means. Each of the components of the light pipe was designed and models were built, studied and altered to achieve maximum capture of daylight. The geometry of the proposed capture component in a light pipe is an innovative solution for bringing daylight into deep areas within buildings in climates of high latitude. Finally the conclusion is presented along with recommendations for further research.

1 OBJECTIVES

As noted the principal objective of this day lighting concept has been to capture as much light as possible where the main source of light is diffused, as is normally the case in countries of high latitude. The introduction of a new geometry in the capture component in a light pipe is an innovative solution for bringing daylight into deep areas within buildings in climates of high latitude. The typical passive solar system to allow light into buildings in climates of high latitude is a large window, (Figure 1). Large windows however tend to provide a lot of daylight near the window and much less daylight further away from the window.

Figure 1 The typical passive solar system used in climates of high latitude

The proposed light pipe is intended to compensate for the lack of daylight in the deeper areas of a building by bringing natural daylight in a controlled manner into these areas.

2 PROPOSAL

The basic design of this passive solar system consists of a geometrically designed head for capturing solar radiation, which also prevents ingress of rain and wind. This light is then re-directed through a vertical mirrored duct and reaches the interior of the building through a diffuser, which distributes the light evenly within a room. Unlike other light pipe systems, the proposed system is efficient at capturing light coming from all directions. This makes it suitable for overcast situations as is commonly found in climates of high latitude.

3 DESIGN DEVELOPMENT

The primary aim of the proposed light pipe is to capture diffused solar radiation in climates of high latitude such as Ireland – Dublin (53.4°N latitude). The design has been developed through the use of 2d drawings, 3d computer models, and 3d physical scale models with the appropriated geometry. The proposed system is based on the study of geometries which are suitable for the capture of diffused daylight. Also every component of the light pipe has been carefully designed to control thermal discomfort, which can also be an issue in climates of high latitude.
The light pipe capture component geometry was varied to study illumination efficiency and distribution. As an additional aspect to the design the aesthetical integration of the proposed light pipe into typical traditional architectural forms (I.e. pitched roofs and chimneys etc) in climates of high latitude has also been considered.

4 CAPTURE COMPONENT

The initial approach of the proposed form is the sphere or the circle, a form that represents the absolute unit, supreme perfection, and a symbol of eternity, the soul. The form of the capture component contemplates the sky (Figure 2) in a spherical form, which is the perfect geometrical shape to capture light coming from all directions (diffused light). The capture element consists of simple conical groupings of mirrors (Figure 3), which has partly been inspired by optimal natural forms/shapes like the eye of insects and partly by the C60 molecular structure (Buckminster Fuller). The form of the eye of an insect consists of a series of approximately 800 facets of hexagonal forms (Figure 4) whose function is to capture information. The geometry of a light-capturing element can be composed of a cone with a hexagonal or pentagonal base with a 2:1:1 proportion. The union of several 'cones' make up the three-dimensional form of a hemisphere of reflecting surfaces which directly relates to the molecular structure of "fullerene" or C60 (Buckminster Fuller - Figure 5). The geometry of the proposed capture component uses several 'cones' to capture light in a relatively small inlet glazing area and transports the diffused daylight efficiently though the pipe component**.** The diffused light travels through each capture element to the transport component and on to the internal spaces.

Figure 2 Capture, the component of the system

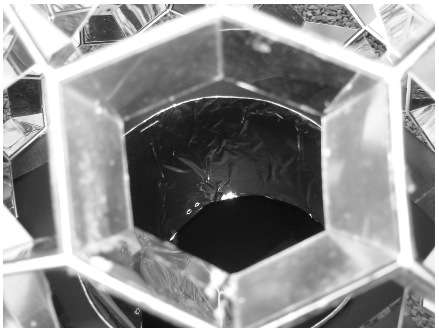

Figure 3 Component of the capture element

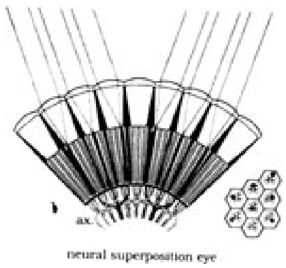

Figure 4 Section through eye of insect

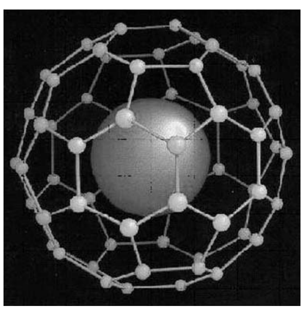

Figure 5 the “fullerene” or also C60 (by Buckminster Fuller)

5 TRANSPORT COMPONENT

The transport component is essentially a vertical hollow mirrored cylinder with high reflection coefficient, which is the most effective coefficient for transporting diffused light. It has a proportional size to the opening, which in this case is the diameter of the hemisphere and it will have a variable height according to the case. Light from the capture component is reflected down the transport component (Figure 6) to the diffuser component.

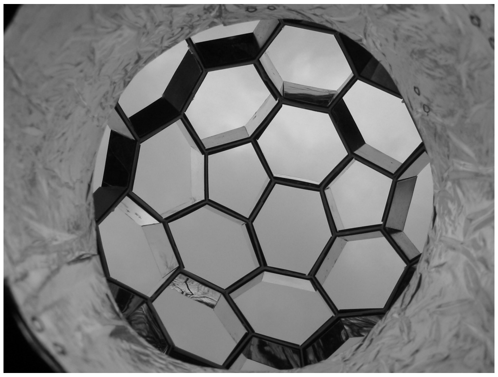
Figure 6 Transport component showing diffused light being reflected from capture component

6 DIFFUSER COMPONENT

And finally the light is distributed in all directions in the space with the help of a diffuser component that increases the user comfort of the space. The diffuser component will be required as in climates of high latitude up to 40% of light could be direct light which needs to be controlled. Also the diffuser component helps to achieve a higher factor of distribution of light within the space (Figure 7).

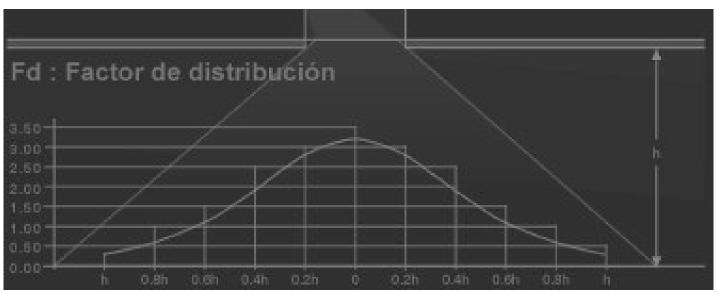

Figure 7 Graphic of distribution of light from diffuser component

7 EVALUATION METHOD

The initial design of the proposed light pipe includes a 3d model for the study of different geometries as well as a three-dimensional computer model (Figures 8 & 9). The design of the light pipe was completed with a physical 3d scale model for the study process and takes into consideration the characteristics and benefits of the proposed model, and its comparison with a conventional sun pipe. Considering as a base model the "sun pipe" (Figure 10 – Serra 1999), which is a device that leads direct solar rays into deep areas within buildings which it cannot reach by other means, we have developed this system to work effectively within diffused light situations.
The evaluation method of the study process comprised outdoor tests of the physical scale models. The models were photographed outdoors under overcast sky conditions at representative times of the day in Dublin Ireland (53.4°N latitude). The test evaluates the qualitative daylight performance and distribution in the space. As noted the outdoor tests were performed in over-

cast sky conditions and these tests enable us to obtain an immediate evaluation of the efficiency of the system to visualize the amount of daylight which penetrates the interior space.

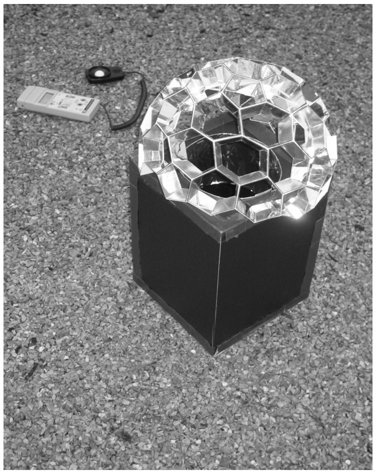

Figure 8-model scale of the proposed daylight pipe

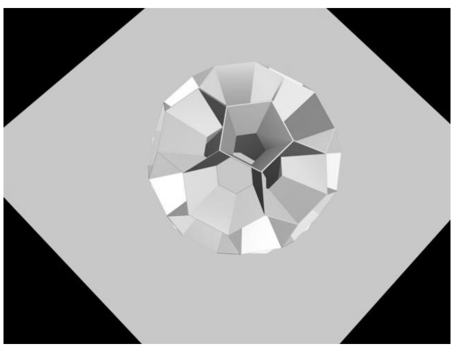

Figure 9 three-dimensional computer model of the proposed geometry for the capture component

Figure 10 Sun pipes (Serra, 1999) Natural daylight system

A complete evaluation of the performance of the system took place in this way through the entire year, especially on the winter and summer solstices (21^{st} of June at 12pm, 21^{st} of December at 12pm and 21^{st} of March at 12pm, 21^{st} September at 12pm).

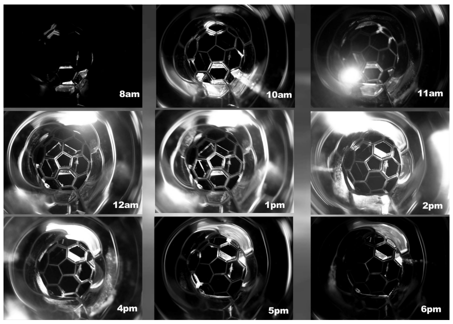

Figure 11 Natural daylight system simulations on 21st of December

8 RESULTS

In general the proposed light pipe performed extremely well in overcast situations throughout the year. Varying results were recorded at different times of the year when the sky was overcast but a high level of luminance was achieved at all times (Figure 12). The proposed system therefore has proved to work efficiently for climates of high latitude.

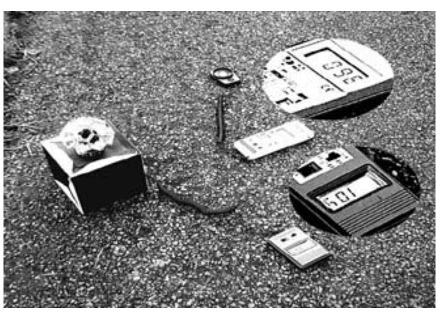
Figure 12- Equipment showing test results

9 AESTHETICAL INTEGRATION OF LIGHT PIPE

Chimneys, which are a traditional architectural element in climates of high latitude, renew the air in a building (Figure 13). A clear similarity to our system is apparent. The light pipe device is located at roof level to gather light from the zenith region of the sky, and like the chimney which is also a vertical architectural element, integrates itself harmoniously within its architectural environment.

Figure 13 Chimneys, typical architectural element in climates of high latitude

10 CONCLUSION

Sunlight is an important factor in the wellbeing of building occupants. Entering via the eyes sunlight stimulates the nerve centre within the brain that controls daily rhythms and moods. Using light pipes in buildings as day lighting devices can bring multi-fold benefits. The application of light pipes produces good value in terms of energy conservation, environment protection, maintaining health (physical and psychological) and improving productivity and work performance. Daylight penetration improvements into the indoor environment can also significantly lessen energy consumption by artificial lighting systems and can improve the overall building performance. Previously light pipes have only worked effectively in climates of lower latitude.
The geometry of the new capture component in the proposed light pipe (Figure 14) has shown that the benefits of light pipes can now be fully realized in climates of higher latitude.
The overall advantages of the proposed system are the following:

- Light pipes constitute a simple technology, which should be utilized in climates of high latitude.
- The consumption of energy used in daylight pipes is minimal (manufacture only) and so they conserve the environment.
- Use of natural Light in internal spaces is positive for health and wellbeing.

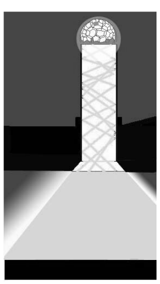

Figure 14 Proposed light pipe in climates of high latitude

REFERENCES

Coch H and Isalgue A, (2000) Sun ducts: new design and applications, World Renewable Energy Congress IV, Brighton UK 489-493

Eben K, (1993)'Let the sun shine in' Lighting Design & Application 23 (5) 41-46.

Espiritu, R. C. (1994) Low illumination experienced by San Diego adults: association with atypical depressive symptoms, Biological Psychiatry, 35, 403-407

Pohl W and Anselm C, (2000) Room illumination by controlled sunlight, Proceedings of 6th World Renewable Energy Congress, Brighton, UK 367-370

Rosemann, A.; Kaase, H.; (2002) Daylight for Building Interiors; Proceedings of the CIE/ARUP Symposium on Visual Environment at the Royal Society, ISBN 3 901 906 16 9; London;

R. Serra, (24-28 de October de 1988) Day lighting components Proceedings of an International Congress held at Sarbrucken, F.R. Germany. Euroforum New Energies,. Published by H. S. Stephens & Associates. Volumen 3 Pg. 343-345.
R. Serra, A. Isalgué, Joan Quílez. (2000) Sun ducts: principles and modelling
Proceedings of International Building Physics Conference, Eindhoven, NL. 299-305
R. Serra, H. Coch, M. Bogatto (2000) Natural light as a decisive factor in the appreciation of environmental comfort Proceedings of PLEA, Cambridge United Kingdom. Architecture city environment. Published by James & James. Pg. 161.
R. Serra, R. San Martin, J. Quilez, I. Martinez. (October 1999) Principles, Modelization and Application of Solar Ducts Presented at REBUILD 99. The Cities of Tomorrow. Barcelona. Spain. Pg. 69-72.
Smith G B, Earp A, Stevens J, Swift P, McCredie G and Franklin J, (2000) Materials properties for advanced daylighting in buildings, Proceedings of World Renewable Energy Congress IV, Brighton UK-Solsona X, Badinier C and Coch H, (1989) New day lighting components; a sun duct in building retrofitting 2nd European Conference on Architecture, Paris, France
Zeguers, J. D. M. and Jacobs, M. J. M. (1997) Energy saving and the perception of visual comfort, Proceedings of Lux Europe

Examination of solar control of existing building stock in Izmir and suggestions for a sustainable future

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ABSTRACT: Solar control is one of the most important steps of creating comfort conditions in buildings to create a sustainable architecture and a sustainable future. Comfort conditions describe the position at which people feel themselves comfortable. The aim of solar control is to detail the orientation, windows and shading elements of the building so they gain minimum heat in the overheated period, and lose minimum heat in the underheated period. By using solar control, buildings provide human needs with the minimum energy use. Therefore the aim of this study is to examine how solar control is used in the existing building stock in Izmir and to propose suggestions for providing comfort conditions with less energy use for a sustainable future. This will be done by describing comfort conditions, solar control and its use in existing building stock in Izmir and a suggestion for a better result will be proposed.

1 INTRODUCTION

Comfort conditions are the important points that help producing a building interior in which people feel themselves well and comfortable. There are different kinds of comfort conditions like thermal, visual and aesthetic comfort. All of them are important but here in this study, thermal comfort will be held and this will be called as comfort conditions only.

The houses have always been heated and lightened by the sun since ancient times. These benefits of the solar rays can be used to supply all of the buildings' requirements by designing a building's orientation, proportions, and materials to take advantage of the sun's path. (Johnson, 1981) This is done with the use of solar control.

Comfort conditions are affected by heat gain from the solar radiation, heat loss from the windows, heat that people produce themselves, humidity of the space, number of air change in the space which is ventilation, etc. As seen, solar control is one of the most important steps of creating comfort conditions in the buildings while trying to create a sustainable architecture and a sustainable future. The aim of solar control is to detail the orientation of the building, its windows and shading elements so that they gain minimum heat in the overheated period (which is summer time), and they lose minimum heat in the underheated period (which is winter time). Thus, solar control helps to have a sustainable future of buildings and architecture due to the fact that with the use of solar control, buildings provide human needs with the minimum energy use. And therefore, these buildings would sustain longer due to the fact that people feel comfortable in these buildings and they are pleased with their houses. Thus, solar control of the existing buildings in Izmir is examined in this study. There are many examples of the use of solar control in buildings like curtains, jalousies, Venetian blinds, trees, green plants, vertical and/or horizontal solar shading elements, glass coating films, etc. They can be grouped into three: the ones that are used inside the building skin (interior), the ones that are used outside the building skin (exterior) and the ones that are used as/in the building skin.

Interior solar shading elements: these are used inside the window. They help decreasing the heating up of the interior a little by not letting solar rays go deep in the building. But solar rays still have entered the interior and since they cannot leave the interior due to the fact that their wavelength changes when they enter the interior and hit a surface. Solar rays may go through the glass when they have short wavelength. When they enter the interior and hit a surface, they share some of their energy with that surface and thus their energy decreases and their wave-length becomes long wavelength. And solar rays with long wavelength cannot get through the window glass. Therefore they stay inside the building and begin to heating up the interior. Therefore interior solar shading elements have a little effect on solar control.

Solar shading elements that are used as/on the building skin: these are some examples like moveable jalousies in the window frames between two glass panes, and some other glass with solar control coatings. These have a better effect on solar shading than interior solar shading ele-ments.

Exterior solar shading elements: these are used exterior of the building. Some examples are Venetian blinds, curtain walls, vertical and/or horizontal shading devices, trees, green plants, etc. These have the best solar shading effect than the other two groups due to the fact that they stop the solar rays before entering the building and keep them outside. Therefore these have the best efficiency and are generally preferred and used mostly in the hot climate zones.

As seen, there are many ways of use of solar control. If solar control is not used, then air-conditioning systems are used and they consume so much energy that much CO2 is released to the atmosphere while it can be avoided by solar control and thus sustainability could be achieved. Due to the fact that Izmir is in a hot-dry climate region, it is necessary to use solar control in order to provide comfort conditions in the buildings. For this purpose, many of these ways are used in architecture. Most of them are added to the buildings after the construction phase due to the fact that solar control has not been thought of during the design phase of the buildings. Therefore they are added to the buildings in the using phase as a result of necessity. All of these uses are examined in the study.

2 EXAMINATION OF CASE STUDIES

Izmir is a very big city with a population of more than 3 million people. Therefore regions of Alsancak and Balcova are taken into consideration in this study in order to compare and show the use of solar control in two different regions with nearly the same orientation.

The first case study is Alsancak. It is near the center of the city and one of the oldest accom-modation areas of the city. The photographs were taken from the famous seaside region known as "Kordon" and the buildings are facing north-west and also the sea.

1a.) and 1b.)

1c.) and 1d.)

Figure 1. Solar shading use examples in Alsancak region

In Figure 1b.), it can be seen that there is a big shadow of the balcony on the facade in the left corner of the photograph. This photograph was taken at around 14:00 in the summer. So it is obvious that balconies are very efficient shading elements. Also in Figure 1a.), and 1c.), it is seen that there are Venetian blinds on the facades of buildings. The top floors of these apartment blocks are being used as houses and the ground floors are for commercial uses. When the people living in these houses come home in the evening, they have a wonderful view of Izmir bay, but they cannot use it until the sunset; because they are facing north-west. Therefore they use Venetian blinds to maintain comfort conditions in their homes. In Figure 1d.), the two big buildings at the Cumhuriyet Meydani (Square) are seen. The one on the left is a hotel with curtain wall facade. The glass on the facade is a reflective coating therefore it helps providing solar control. The other one is the Post Office building and its facade has shading elements on its facade.

The second case study is Balcova. It is a long way from the city center but in the city border. It was a green area where vegetables were planted about 25-30 years ago. Most of the oldest buildings date back to 1980's. It is examined in two examples. The first one is the housing area around Serafettin Izmir Park which is under the well-known Teleferik region.

2a.) and 2b.)

2c.) and 2d.)

Figure 2. Solar shading use examples in Balcova region

In Figure 2a.), and Figure 2c.), south-east facades of the buildings are seen. There are Venetian blinds on the windows as well as green plants on the facade to protect the building from excess solar energy.

In Figure 2b.), south-east and north-east facades are seen. There are Venetian blinds on all of the windows except the balconies. The big balconies provide shade to the interior.

In Figure 2d.), south-west and north-west facades are seen and there are Venetian blinds on nearly all of the windows on these facades of the buildings. They are not original; they were added to the buildings after the construction during the using period.

The second case study area of Balcova is near the Teleferik road near Serafettin Izmir Park housing region. This is a housing complex. It was constructed during 1980's, and solar control was not thought of until the using period of the buildings.

 

3a.) and 3b.)

 

3c.) and 3d.)

Figure 3. Solar shading use examples in Balcova region

Figure 3a.) and 3b.) show the south-west facade of this building complex. Their windows weren't protected against excess solar rays at their construction phase. But due to the fact that solar rays overheat the interior and disturb people so much that they added Venetian-blinds on not only this facade, but also on the south-east and north-east facades as seen in Figure 3d.) and 3c.) respectively.

3 A PROPOSAL FOR THE SUSTAINABILITY OF EXISTING BUILDINGS IN IZMIR

As seen in these case studies, there is solar control in most of the houses in Izmir. Here, a new method is being proposed for the sustainability of these buildings. What is being proposed here is to use photovoltaic (PV) components for the solar control in these buildings instead of existing Venetian blind covering elements. (Altin, 2005) This will make these buildings produce their energy need from excess solar energy that is not desired. This is an advantageous way of solar control due to the fact that the buildings' energy requirements are provided with the unwanted solar energy in the overheated period. In addition to this, their mounting systems are ready on the windows due to the fact that they can be mounted on the mounting system of the existing Venetian blinds.

The photovoltaic components are the elements that produce electricity from solar radiation directly without the need for any other energy resource and without any harmful emissions to the environment. They can be used as solid panels or they can be used on flexible coating for example to coat a round column… These uses are suitable for external solar shading. PV cells can also be used between two glass panes and this use is suitable for the solar shading as/on the building skin. They can be used directly on the window glass. But this type has a disadvantage which is not being able to remove the solar shading when the solar rays are required in the underheated period (in winter).

4 CONCLUSION

Solar control is necessary in houses in hot-dry climates like in Izmir. It is necessary in the overheated period, but not necessary and generally not wanted in the underheated period. Solar control is being used in many of the houses in Izmir as Venetian blinds. If these blinds are replaced with photovoltaic components, this would be a beneficial step due to the fact that required electrical energy would be produced from the undesired solar energy in the overheated period. Besides they can be opened and would not be used during the underheated period thus giving the chance to the interior of the building to be heated during this time. Not producing electricity does not matter because in the underheated period, the amount of solar radiation is so little that the electricity that might be produced would be very little and the fact that it is not being produced does not change much thing. Therefore, replacing the Venetian blinds on the windows of existing building stock in Izmir is proposed in this study for a more sustainable future and a more sustainable architecture.

REFERENCES:

Altin, M., 2005, *Research On The Architectural Use Of Photovoltaic (Pv) Components In Turkey From The Viewpoint Of Building Shape,* Izmir: Dokuz Eylul University Ph.D. Thesis

Johnson, T.E., 1981, *Solar Architecture: The Direct Gain Approach*, USA: McGraw Hill Book Company.

Olgyay, A & Olgyay, V., 1957, *Solar Control and Shading Devices,* USA: Princeton University Press.

Olgyay, V. & Olgyay, A., 1973, *Design with Climate: Bioclimatic Approach to Architectural Regionalism,* USA: Princeton University Press.

Energy consumption of RC buildings during their life cycle

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ABSTRACT: Studies on the total energy use during the life cycle of reinforced concrete buildings are desirable, considering the urgent necessity to save energy. Life cycle of buildings includes different phases which are the manufacture of the building materials, transportation, construction of the building, occupancy, renovation, demolition and removal of the materials from debris. However, there have been few studies are on the total energy use during the life cycle of buildings. Researches are mainly focused on the energy use for buildings during their period of use. In the present study, the total energy use of ordinary reinforced concrete buildings in Izmir during their life cycle is investigated and their energy consumptions are calculated for all temporal phases separately.

1 INTRODUCTION

The optimum use of limited energy sources is one of the most vital issues for the modern countries. The increase in global warming, energy resource depletion, and local and regional pollution have detrimental effects on the ecological system since the late 1980s. Buildings have a great role in global and local energy consumption of the world and energy savings in buildings has gain importance in last decades.

Energy used during the lifespan of buildings consists of consumed energy in production, management and destruction phases (Fig. 1). Production energy may be divided into three parts: material manufacturing, transportation and erection energy. Management energy is the energy used during occupation and renovation of building. Occupation energy mainly includes the energy used for heating, ventilation and household electricity. Obsolescence, natural or man-made catastrophe and out-of-fashion facilities causes the renovation of building. Destruction energy is the energy use for the demolition and removal of debris processes at the end of the lifespan of buildings.

There have been few studies are on the total energy use during the life cycle of buildings. Researches on the energy use for buildings are mainly focused on management phase. In the present study, the total energy use of three ordinary reinforced concrete buildings in Izmir during their life cycle is investigated and their energy consumptions are calculated for all temporal phases separately. Therefore, it is often useful for a designer to have a tool, which will allow a building to be assessed at the design stage, so that various design options and strategies can be compared with one another based on the performance over their useful lifetime.

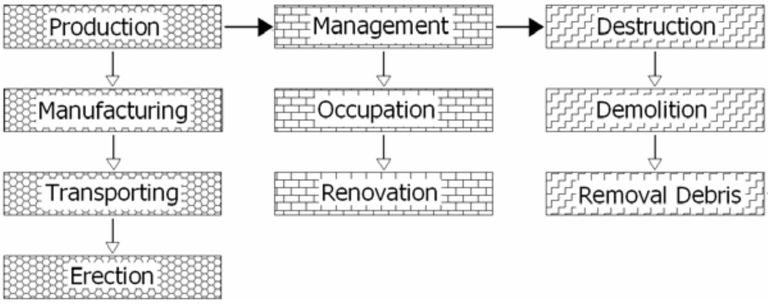


Figure 1. Life cycle phases of a building

2 METHOD

Life cycle of building includes the manufacture of building materials, transportation of building materials to construction site, erection of building, occupancy, renovation, demolition and removal phases. Energy demand during the life cycle of the building $Q_{life\ cycle}$ (kWh), is the sum of the different energy demands during the different phases and calculated as below.

$$Q_{life\ cycle} = Q_{manufacture} + Q_{transportation,\ production} + Q_{erection} + Q_{occupation} + Q_{renovation} + Q_{transportation,\ renovation} + Q_{demolution} + Q_{transportation,\ removal} \quad (1)$$

Since there is not enough data about the energy gained by reuse, recycling or combustion, the value of the left over products are neglected. The procedure used for calculating energy consumption in all these phases is described below.

2.1 *Energy consumption in production phase*

Energy is required for manufacturing any construction material. The manufacturing energy requirements of some construction materials are presented in Table 1. The waste of each material produced during the erection of the building is also shown in the same table. The waste is expressed as a waste factor w_i. The energy requirement for manufacturing any the building material $Q_{manufacture}$ (kWh) can be calculated as follows (Adalberth, 1997):

$$Q_{manufacture} = \sum_{i=1}^{n} m_i \left(1 \pm w_i / 100\right) M_i \quad (2)$$

where n = number of materials, *i* = the material of concern, m_i = amount of the building material *i* (ton), w_i = the factor for waste of the building material *i* produced in erection (%), and M_i = energy required for manufacturing the building material *i* (kWh/ton).

Table 1. Energy use for building materials

Materials	M_i (kWh/ton)*	w_i (%)**
Reinforced Concrete	560	20
Plain Concrete	210	10
Tiles and clinkers	2000	10
Glass	7230	0
PVC	24650	5
Polystyrene	29650	10
Coatings: Paints and lacquers	7000	5
Steel	8890	5
Electric wires, copper	19780	5
White goods, 1110 kWh/per item	-	-

* Source: Andersen et al., 1993

** Source: Larsson, 1983

Energy is required for moving construction materials from one place to another. Transport takes place from the manufacturer to the building site, when the building is being erected or renovated. The transportation of raw and semi-manufactured materials is included to the manufacturing energy. Various energy uses associated with different kinds of transportation is shown in Table 2.

Table 2. Energy use for transportation of building materials

Transportation	T_c (kWh/ton km)*
Long Distance Road (distances > 50 km)	0.28
Long Distance Road (distances ≤ 50 km)	0.75

* Tillman et al., 1991

The energy use for transporting the building materials $Q_{transportation,erection}$ (kWh) to and from the building site in erection can be calculated as follows (Adalberth, 1997):

$$Q_{transportation,erection} = \sum_{i=1}^{n} m_i \left(1 + w_i/100\right) d_i \; T_c \tag{3}$$

where n = number of materials; i = the material concerned; m_i = amount of the building material i (ton); w_i = factor for waste of the material i produced during erection of the building (%); d_i = distance from the manufacturer of material i to the building site (km) and T_c = energy required for the conveyance concerned (kWh/ton km).

Energy is needed for many erection stages of a building such as for instance drying and drainage, the heating of sheds and of the building itself, electricity for lighting purposes and for machinery, and so on. The energy pertaining to the various processes are given in Table 3.

Table 3. Energy consumption for various processes

Materials	P_i *
Drying of standard concrete on building site	44 kWh/ton
Drying of concrete element	25 kWh/ton
Excavation and removal of soil	32 kWh/m^3
Smoothing of soil	3 kWh/ton
Lighting of construction object	26 kWh/m^2 usable floor area

* Source: Andersen et al., 1993

The energy use for different processes in erection of a building $Q_{erection}$ (kWh) is estimated as follows (Adalberth, 1997):

$$Q_{erection} = \sum_{k=1}^{m} p_k P_k \tag{4}$$

where m = number of processes; j = the type of process; p_i = the amount of the process j (ton, m^3 or m^2 usable floor area); and P_j = energy required for the process j (kWh/ton, kWh/m^3 or kWh/m^2 usable floor area).

2.2 *Energy consumption in management phase*

Management includes occupation and renovation phase of a structure. Energy used in occupation has many components but in the present study only heating and electricity energy are considered. The heating energy demand of buildings is calculated according to Turkish Standard TS825-Thermal Insulation of Buildings (1999). Due to there is no detailed investigation on electricity consumption for example buildings, general consumption values are used.

According to Turkish Republic Prime Ministry State Planning Organization (2003), annual electricity consumption is 3000 kWh/person for Izmir region. The energy needed during the occupation phase, $Q_{occupation}$(kWh), is obtained by multiplying the energy use per year, $Q_{occupation}$ (kWh/year), by the life-span of the building concerned, in this case 50 years:

$$Q_{occupation} = 50.Q_{occupation,annual} \quad (5)$$

When the energy use during the renovation of a building is calculated, some assumptions regarding the life-span of the various construction materials have to be made. Life-spans of some materials are given in Table 4.

Table 4. The life spans of construction materials

Life span of building	Life span (annual)*
Life span of building	50
Frame (External walls, internal walls, insulation)	50
Parquet flooring	50
Water pipes and electric wires	50
Ventilating channels	50
Facing: wooden paneling	30
Windows and doors	30
Wardrobes and cupboards	30
Roofing tiles and drainpipes	30
Plastic carpeting	17
Water heater	16
White goods	12
Painting and wallpapering	10

* Source: SABO, 1992

The energy use for producing the building materials during the renovation, $Q_{renovation}$ (kWh), is estimated as follows (Adalberth, 1997):

$$Q_{renovation} = \sum_{i=1}^{n} m_i (1 + w_i/100) M_i \left(\frac{\text{life span of a building}}{\text{life span of material}_i} - 1 \right) \quad (6)$$

The energy use, $Q_{transportation,renovation}$ (kWh), for transporting the building in renovation is estimated as follows (Adalberth, 1997):

$$Q_{transportation,renovation} = \sum_{i=1}^{n} m_i (1 + w_i/100) \left(\frac{\text{life span of a building}}{\text{life span of material}_i} - 1 \right) (d_i + 20) T_c \quad (7)$$

2.3 *Energy consumption in destruction phase*

Destruction phase includes demolishing and removing debris from the building site. The energy use for demolishing the building $Q_{demolition}$, (kWh), is estimated as follows (Adalberth, 1997):

$$Q_{demolition} = \sum_{k=1}^{m} p_k P_k \quad (8)$$

where m = number of processes; j = the type of process; p_i = the amount of the process j (ton, m^3 or m^2 usable floor area); and P_j = energy required for the process j (kWh/ton, kWh/m^3 or kWh/m^2 usable floor area).

The energy use, $Q_{transportation, demolition}$ (kWh), for transporting the building in renovation is calculated as follows:

$$Q_{transportation,demolition} = \sum_{i=1}^{n} m_i \left(1 + w_i/100\right) 20\, T_c \quad (9)$$

20= the assumed distance from the building site to the waste disposal site (km); and T, = energy required for the conveyance concerned (kWh/ton km).

3 NUMERICAL EXAMPLE

In the present study, the energy use of three reinforced concrete dwelling buildings during their lifespan is investigated. Floor plans of these buildings are shown in Figure 2, Figure 3 and Figure 4.

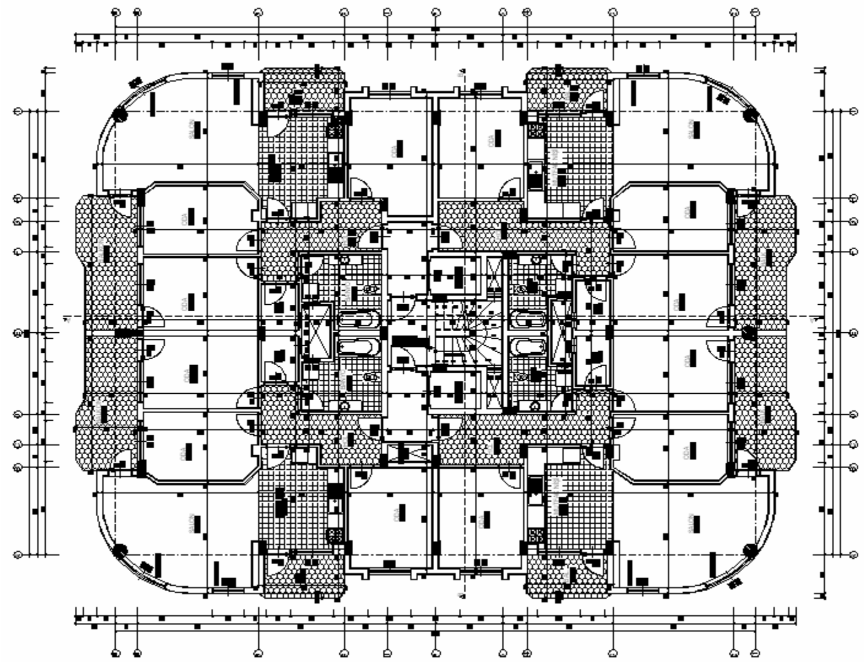


Figure 2. Building Plan 1

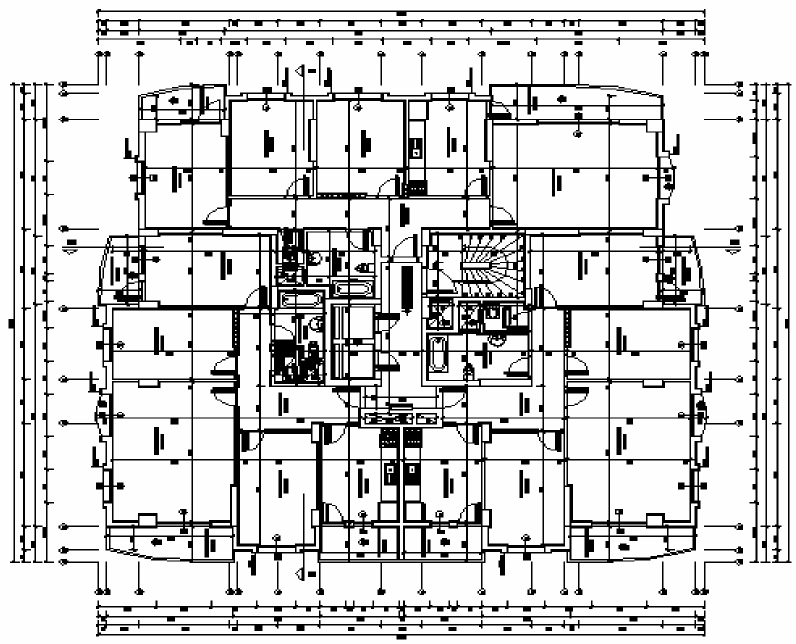


Figure 3. Building Plan 2

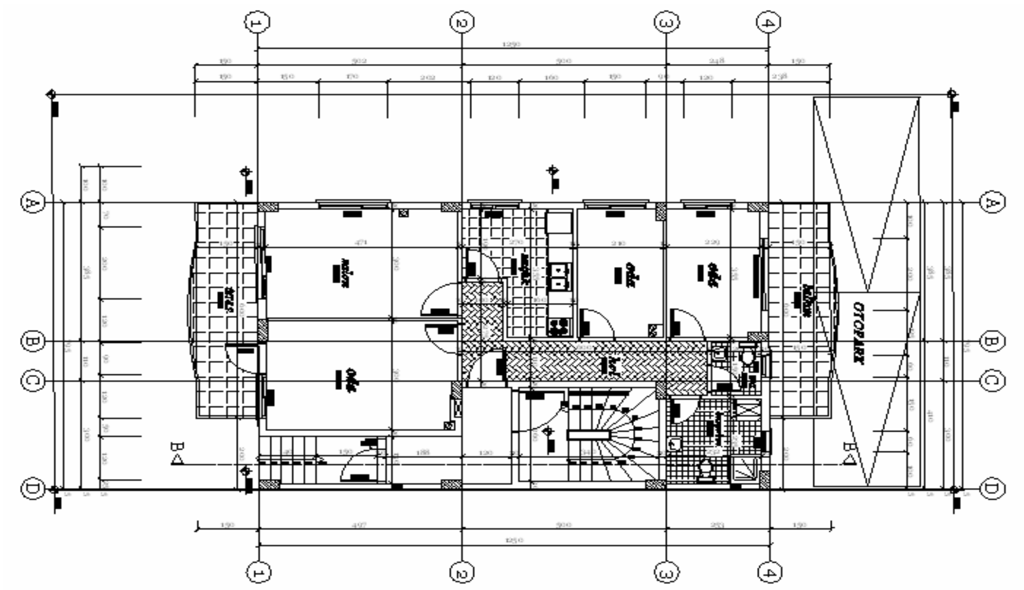


Figure 4. Building Plan 3

All buildings are in Izmir region. Some characteristic properties of buildings are summarized in Table 5.

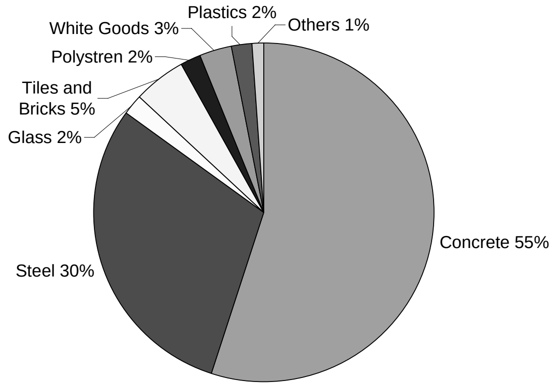
Table 5. Properties of buildings

	Building 1	Building 2	Building 3
Floor Area (m^2)	410	450	100
Number of floors	10	6	5
Number of apartments	40	24	5
Number of residents*	144	86	16
Source of heat	District Heating	District Heating	District Heating
Heating system	Radiators	Radiators	Radiators

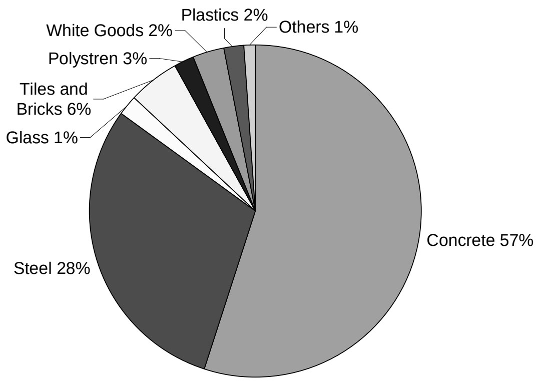
* The number of residents is estimated according to Turkish Prime Ministry State Planning Organization Reports (2003). In the city of Izmir, approximately 3.6 person living in each apartment.

The amounts of materials consumed for erection of each building was calculated. The quantities of the building materials are substituted into Equation 2 in order to determine manufacture energy of materials for each building and calculated energies for materials are presented in Figure 5.

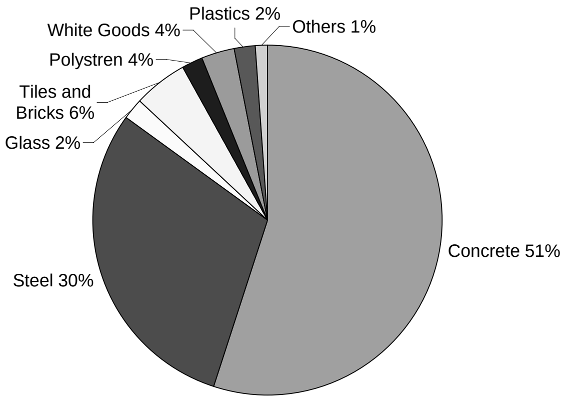
Only heating and electricity energies are considered in calculating occupation energy of buildings. The heating energy demand of buildings was calculated according to Turkish Standard TS825 (1999). There is no detailed investigation on electricity consumption for buildings. For this reason, the approximate energy consumption value published by Turkish Republic Prime Ministry State Planning Organization is used. According to this organization report, electricity consumption is 3000 kWh per person for Izmir region. This value is multiplied by number of residents and annual electricity consumption of each building is calculated.



Building 1 : $Q_{manifacture}$= 1066 kWh/m^2 for 50 years



Building 2 : $Q_{manifacture}$= 1202 kWh/m^2 for 50 years



Building 3: $Q_{manifacture}$= 1396 kWh/m^2 for 50 years

Figure 5. Energy used for manufacture the construction materials for life cycle of buildings

The energy used in production, management and destruction phases are calculated and summarized in Table 6. It is seen from this table that the most energy is consumed in management phase for all buildings. Results also show that the total energy consumption of each building is 162, 157 and 182 kWh/(m^2 .year) respectively.

Table 6. Energy use during life cycle of buildings

	Building 1		Building 2		Building 3	
Phases	kWh/m^2	%	kWh/m^2	%	kWh/m^2	%
Production						
Manufacture	1066	13.2	1202	15.4	1071	11.8
Transportation	31	0.4	34	0.4	28	0.3
Erection	148	1.8	159	2.0	143	1.6
Management						
Occupancy, 50 years	6470	80.0	6086	77.8	7098	78.2
Renovation	341	4.2	313	4.0	707	7.8
Destruction						
Demolition	10	0.1	11	0.1	9	0.1
Removal	21	0.3	23	0.3	19	0.2
Total kWh/(m^2.50 years)	8088	100	7827	100	9075	100
Total kWh/(m^2.year)	162		157		182	

4. CONCLUSIONS

In this paper, the total energy use during the life cycle of the three buildings in Izmir region is investigated. The purpose is to gain an insight into total energy use for buildings during its life cycle. The energy used for concrete and steel is 85%, 85% and 81% of the buildings and these are composing the main part of the manufacturing phase. The results show that management phase is the highest energy consumption phase for all buildings. For this reason, using less heating and electricity energy is very important for minimizing life cycle energy. It is also obtained that total energy use of buildings are 162, 157 and 182 kWh/(m^2.year) and energy use is increasing when the total useful area of building is decreasing .

REFERENCES

Adalberth, A. 1997. Energy use during the life cycle of buildings: A Method. *Building and Environment*. Vol. 32, No. 4, pp.317-320.

Andersen, S., Dinesen, J., Hjort Knudsen, H. & Willendrup, A. 1993. *Livscyklus-baseret bygningsprojektering.* Report no 224, Danish Building Research Institute, Hersholm, Denmark.

Larsson, B. 1983. Materialforbrukning Pa Byggarbetsplatsen. *Building Economics And Construction Management,* Chalmers University Of Technology, Gothenburg, Sweden.

SABO. 1992. *Maintenance norm*. Organization For Municipal Housing Companies, Stockholm, Sweden.

SPO, 2003. *Development report for city of Izmir*. Turkish Republic Prime Ministry State Planning Organization. Available: http://www.dpt.gov.tr/bgyu/ipg/ege/izmirPER.pdf.

Tillman, A.-M., Baumann, H., Eriksson, H. and Rydberg, T. 1991. *Packaging and the environment life cycle analyses of selected packaging materials quantification of environment loadings*. SOU 1991:77, Chalmers Industriteknik, Chalmers Teknikpark, Gothenburg. Sweden.

TS825. 1999. *Thermal Insulation of Buildings*. Turkish Standard Institute. Ankara. Turkey.

Poly-optimal method of designing environmentally friendly buildings

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ABSTRACT: The main topic of this paper is the description of a method for choosing the optimal technology for construction of buildings fulfilling the criterion of minimum usage of total cumulated energy and minimum emission of carbon dioxide in the whole life cycle of the building, taking into account constraints regarding costs. Within the framework of this scientific project four major tasks were undertaken and performed: estimation of emission of carbon dioxide and of values of energy consumption for main technologies and materials by means of LCA, elaboration of a poly-optimal method of construction of environmentally friendly buildings and creation of a computer program.

1 INTRODUCTION

The main goal of the discussed decision problem is optimal choice of elements of a building. As a basic criterion of choice of appropriate materials a rule of equalizing three global coefficients: cumulated energy (E), emission of carbon dioxide (C) and construction costs (K) is used. These coefficients depend on actual configuration of a building represented by a vector of decision variables x. Formally such a problem belongs to a category of multi criteria optimization which after introducing weighted goal function F(x) can be described as:

find optimal configuration x ensuring minimal total cost of a building

$$\min \quad \mathrm{F}(\mathbf{x}) = w_\mathrm{E}\,\mathrm{E}(\mathbf{x}) + w_\mathrm{C}\,\mathrm{C}(\mathbf{x}) + w_\mathrm{K}\,\mathrm{K}(\mathbf{x}) \tag{1}$$

taking into account constraints resulting from available construction technologies.

Weighs in this formula are positive scaling coefficients. Moreover w_E and w_C also include appropriate units recalculating energy and carbon dioxide emission to subsidiary costs. Functions E, C and K are sums of unit costs of individual components. Choice of decision vector which characterize actual configuration of the building unequivocally can be troublesome. Natural solution of this problem are binary variables x_i=0 or 1, which mean presence or absence of a particular component. Taking this into account function K can be written as a sum of unitary costs:

$$\mathrm{K}(\mathbf{x}) = \sum_{i=1}^{N} k_i x_i\ . \tag{2}$$

In the same way we define functions of energy and carbon dioxide emission. Restrictive conditions take in this case the following form:

$$\sum_{i\in D} x_i = 1\,, \tag{3}$$

which is equivalent to the choice of exactly one alternative of a class of components (for example wooden or aluminium window). Finally mathematical model of decision problem leads to binary programming. The major difficulty in such approach is large number of decision variables. Genetic programming which enable effective search of the set of acceptable solutions can be an alternative for direct methods of binary programming.

2 DESCRIPTION OF THE GENETIC ALGORITHM

The performance of the genetic algorithm can be shortly described as follows. First the appropriate coding system of the permissible solutions in the form of sequences of symbols represented by binary chains of the prescribed length is introduced. Such an ordered sequence of genes is called a chromosome or a representative and in a unique way it represents exactly one of the permissible solutions of the problem. In the same time the initial set of the representatives, the so called initial population, as wide as possible is randomly generated. Then in the iterative way according to the prescribed rules the subsequent populations (generations) are obtained. It the passage from population of parents to population of descendants three genetic operations are performed: (1) cross-breeding in the form of exchange of genes, (2) mutation in the form of random disturbance of genes, (3) selection in the form of elimination of weak representatives. It should be stressed that though operations are random in their nature they enable to improve both the overall status of the population as well as the status of the best representative (leader). The so called adaptation function that is directly correlated with the goal function of the primary problem, decides if the considered representative is strong or weak. As a result the subsequent populations of a genetic algorithm display the convergence to the global optimum of the goal function. Due to the popularity of genetic algorithms we omit here further descriptions referring to the article bibliography (e.g. Burczyński 2000, Burczyński 1999b, Goldberg 1989, Schaefer 1999). Instead we focus on the particular elements that result from the peculiarity of the analyzed decision problem.

In the described optimisation method the key problem is the way in which chromosomes are coded enabling full and unique projection of the set of permissible solutions on the set of binary chains and choice of appropriate adaptation function. In the presented paper it is assumed that each class of components corresponds to single gene with minimal chain length which enables to write all possible alternatives for that class. Because n-bits gene enables to write 2^n different alternatives, it is possible that surplus alternatives will occur which does not have equivalents in the set of permissible solutions. For example when class includes 5 alternatives we need to code it 3 bits which enables to represent $2^3=8$ different alternatives, three more than needed. These surplus alternatives are coded with an aid of penalty function, by giving them very high costs of energy and emission. They will be automatically eliminated in the subsequent selection operations of the genetic algorithm.

In fact classical genetics algorithms are used to globally maximize function of adaptation. In the described problem we search for minimum value of total cost of the whole building. We need to perform appropriate transformation. In the presented paper adaptation function is built dynamically, independently for each population based on formula:

$$G(\mathbf{x}) = \frac{F_{\max} - F(\mathbf{x}) + \varepsilon}{F_{\max} - F_{\min} + \varepsilon}, \tag{4}$$

in which F_{max} and F_{min} denote subsequently maximal and minimal value of goal function in the given population and ε is a very small integer number used to avoid division by zero. It is worth mentioning that such function is normalized in such sense that the best element of each population (leader) corresponding to F_{min} will be having adaptation function equal one ($G(x_{min}) = 1$) and the weakest element corresponding to F_{max} will be having adaptation function close to zero. Such approach assures good differentiation of elements of population.

3 PRACTICAL IMPLEMENTATION OF THE OPTIMAL METHOD

The analysis is based on the tentative architectural and construction project designed in accordance with the currently effective construction law and a detailed cost calculation.

It is assumed that changes of the material variants of the structure's elements are possible, however the shape of the building, it's orientation and location on the ground are not subject to the optimal method and therefore will not be changed as a result of applying it.

Basic dimensions in the axis of the partition should remain unchanged, and the usable area as well as the cubic capacity of the building may vary slightly due to differences in the wall and ceiling thickness between the material variants.

The life of the building was set to 50 years.

A starting point of the optimal method is the illustrative scheme of the building, describing all the elements of the building's structure necessary for it's construction from the moment of acquiring the building permit till the partial completion e.g. for the residential building that would be the phase without the floors, external doors and inner finishing (that's the most common state of the apartment handed to the client by the developer).

The details in the division to the elements of the building's structure depends on the future user of the described here optimal method and has significant influence on it's precision.

For each element of the structure (walls, ceilings, roofs etc.) a possibility of choosing material variants within one technology is given. In the Figure 1 a part of the illustrative scheme of the building is presented. For each branch of the decision tree created by the designer (look at graph 1) a set of the following parameters is determined:

- E_i – cumulated energy of the element of the building's structure for the „i" material variant,
- C_i – cumulated carbon dioxide emission of the element of the building's structure for the „i" material variant,
- K_i – cost of producing an element of the building's structure for the „i" material variant.

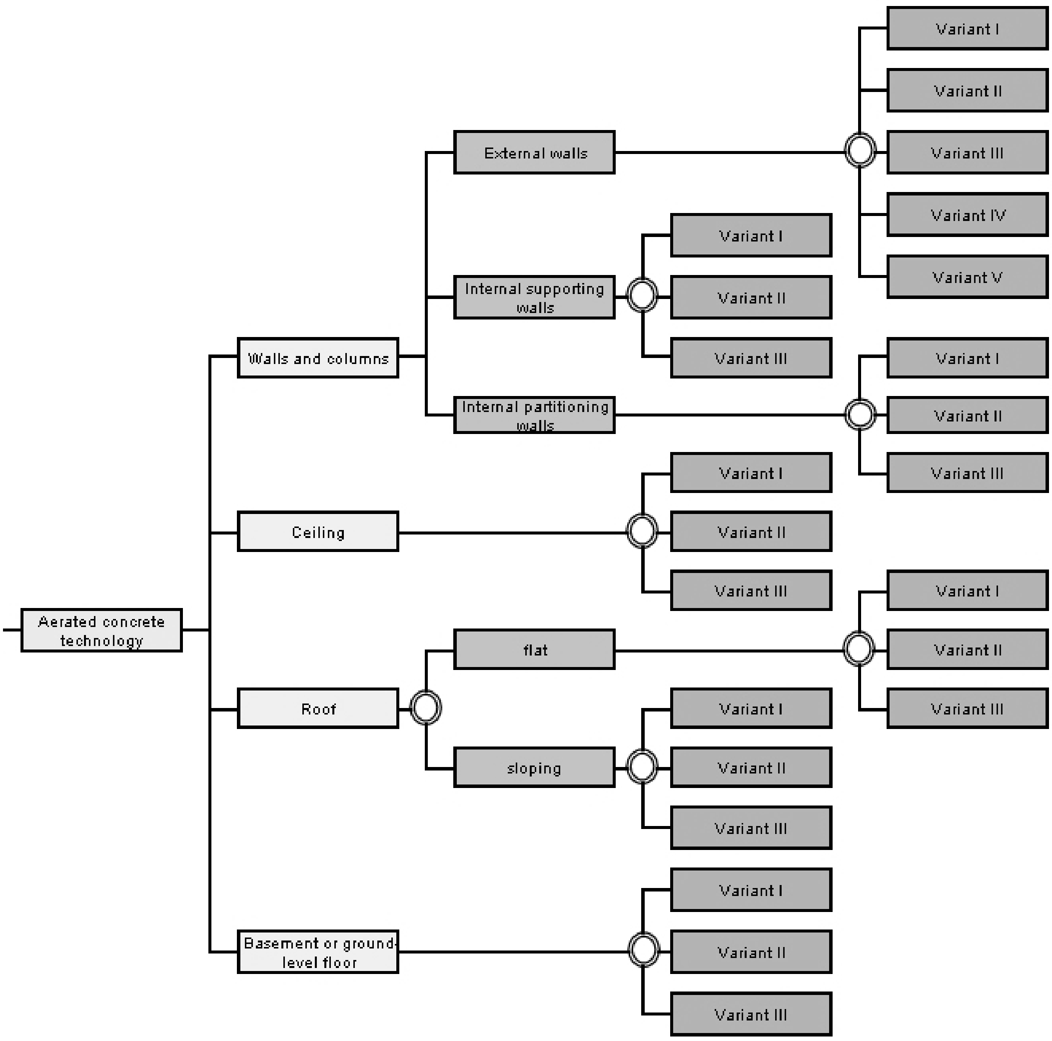

Figure 1. Part of the decision tree

As a result a set of data is created for the decision problem defined with the dependencies (1), (2), (3). The problem defined in this manner may now be solved using the algorithm described in point 2.

Based on general rules describing genetic algorithms (e.g. Burczyński 1999a, Holland 1975, Michalewicz 1996, Stadnicki 2006) and the described above idea of coding of binary chains and the rule for adaptation function computer code was created. It enables efficient solution of the described decision problem. The code was written in Visual Basic for Applications and can be used in Excel environment. A practical example is presented in Fig. 1.

4 EXAMPLE OF THE FUNCTIONING OF A GENETIC ALGORITHM

The numerical example regards a single family house. For the purpose of the example, it was assumed that this is a brick house constructed out of small, ceramic, silicate or aerated concrete elements with wooden, PVC or fibreglass glassed-in areas. Elements of the structure include: walls and columns, ceiling, roof, basement or ground-level floor. The material variants of the elements of the structure are characterized by: thickness of construction layers, thickness and type of insulation materials. In order to meet the requirements of the optimization method, a database containing information about the elements of the building and the parameters describing these elements was created. A part of the database regarding the example given in this paper is presented in Table 1. The first column contains the type of constructional element of the building (class), whilst the next shows the values of corresponding cumulated energy (E_i [MJ/m^2 of structure element area]), cumulated CO_2 emissions (C_i [kg CO_2/m^2 of structure element area]) and the cost of production of an element of the structure using a given technology (K_i [PLN/m^2]) for various materials variants.

Table 1. Example of a database of the elements of a building– aerated concrete technology

Element of the structure	E_i	C_i	K_i	E_i	C_i	K_i	E_i	C_i	K_i
	Variant I			*Variant II*			*Variant III*		
External walls	1480	99	286	1739	131	333	558	22	254
	Variant IV			*Variant V*			*Variant VI*		
External walls	817	54	300	558	22	310	817	54	356
	Variant I			*Variant II*			*Variant III*		
Internal supporting walls	1371	88	141	1256	78	131	1141	69	112
	Variant I			*Variant II*			*Variant III*		
Internal partitioning walls	910	50	53	461	38	53	290	70	44
	Variant I			*Variant II*			*Variant III*		
Ceiling	809	125	359	927	152	419	938	146	363
	Variant IV								
Ceiling	1089	179	423						
	Variant I			*Variant II*			*Variant III*		
Sloping roof	392	226	221	652	258	226	1044	75	311
	Variant IV			*Variant V*			*Variant VI*		
Sloping roof	1303	106	316	751	72	290	1859	165	250
	Variant I			*Variant II*			*Variant III*		
Basement or ground-level floor	876	101	271	1056	128	310	908	105	271
	Variant IV			*Variant V*			*Variant VI*		
Basement or ground-level floor	1088	132	351	1238	122	325	1418	149	365
	Variant VII			*Variant VIII*					
Basement or ground-level floor	552	67	294	552	67	334			

	Variant I			*Variant II*			*Variant III*		
Windows and glassed-in areas	1185	98	700	1368	112	950	1318	101	1050
	Variant IV			*Variant V*			*Variant VI*		
Windows and glassed-in areas	2191	132	400	2374	146	543	2324	135	600
	Variant VII			*Variant VIII*			*Variant IX*		
Windows and glassed-in areas	1834	131	550	2017	146	746	1967	135	825

For every element of the structure there is at least one material variant for its execution. For example, the following material variants were assumed for the ceiling of the tested building:

- Variant I - 24 cm ceiling board Ytong P3, 3 500 + Styrofoam + cement-calcium sulphate plaster;
- Variant II - 30 cm ceiling board Ytong P3, 3 500 + Styrofoam + cement-calcium sulphate plaster;
- Variant III - 24 cm ceiling board Ytong P4, 4 600 + Styrofoam + cement-calcium sulphate plaster;
- Variant IV - 30 cm ceiling board Ytong P4, 4 600 + Styrofoam + cement-calcium sulphate plaster.

The database containing the values of parameters (E_i, C_i, K_i) for elements of the structure of a specific building, taken from the architectural plan, provides the base information for the computer program. In the analyzed case the database contained 100 records. On the basis of this database, the length of the binary chain was calculated, and the preliminary population was generated. Next, subsequent populations were generated in accordance with the described genetic algorithm until the optimal solution was stabilized. In the various numerical tests that have been carried out thus far, convergence was achieved after approximately 70-80 populations. Finally, in the presented example, as a result of the work of the genetic algorithm the decision was made for the building to be constructed according to aerated concrete technology. The results of the analysis for the optimal construction variant are collected in Table 2.

Table 2. Optimal solution - aerated concrete technology

Element of the structure	*E*	*C*	*K*	*Description of the element of the structure*
External walls	*Variant III*			2-layered wall: 24 cm cellular concrete 500, 18 cm Styrofoam, plaster
	558	558	558	
Internal supporting walls	*Variant III*			24 cm cellular concrete 600 + plaster
	1141	1141	1141	
Internal partitioning walls	*Variant III*			10 cm plaster-and-card board
	290	290	53	
Ceiling	*Variant I*			24 cm ceiling board Ytong P3, 3 500 + Styrofoam + concrete-calcium sulphate plaster
	809	125	359	
Sloping roof	*Variant I*			Tar board 0,004 + pine floorboards 0,025 + Styrofoam + fibreboard 0,02
	392	226	221	
Basement or ground-level floor	*Variant VII*			Pine floorboards 0,025 + screed 0,015 + Styrofoam + anti-damp insulation concrete slab 0,15+sand 0,015
	552	67	294	
Windows and glassed-in areas	*Variant IV*			Wooden frame, low-emission pane with argon U=1,1
	1185	98	700	

5 CONCLUSIONS

Designing of environment-friendly buildings is a complex process that needs combining of architectonic and town-planning requirements with the ecological and technological ones as well as it necessitates to apply multi-criteria optimization. For the correct solution of problems connected with designing of such a buildings the use of the computer method is necessary. In the paper the solution based on the genetic algorithms has been successfully applied. Genetic and evolution algorithms have become the universal and widely used tool in the global optimization of functions. Usage of the methods that are based on natural selection, cross-breeding and mutation enables an effective search in the domain of the admissible solutions. A feature that distinguishes the genetic and evolution algorithms among other methods of optimization is looking for the best solution starting from some population of points in the solution space not from the single point. This feature decides about high efficiency of these methods what has been also proved in the presented work. Additional results of the research are computer database containing the values of accumulated total energy for the main technologies and structural materials used in Poland as well as the database that contains the values of CO_2 emission coefficients for the main processes and structural materials most often used in Poland.

The article presents results obtained within a frame of research entitled “Poly-optimal design method of environmentally friendly buildings”. This research has been financed from state budget for science in years 2005-2006 as a research grant 4 T07E 028 28.

6 REFERENCES

Burczyński T., Evolutionary algorithms: application in mechanics, Materials of the Conference „Methods of Artificial Intelligence in Mechanics and Mechanical Engineering, Gliwice 2000.

Burczyński T., Kokot G., The evolutionary optimization using genetic algorithms and boundary elements, Proc. 3rd World Congress on Structural and Multidisciplinary Optimization, Buffalo USA, 1999.

Burczyński T., Orantek P., Algorytmy genetyczne i hybrydowe, Materials from the Seminar. „Sieci neuronowe, algorytmy genetyczne, zbiory rozmyte”, Rzeszów, 1999.

Goldberg D.E., Genetic Algorithms in Search, Optimization, and Machine Learning, Addison-Wesley Publ. Comp. Inc., 1989.

Holland J.H., Adaptation in natural and artificial systems, The University of Michigan Press, Ann Arbor, 1975.

Michalewicz Z., Algorytmy Genetyczne + Struktury Danych = Programy Ewolucyjne, WNT, Warszawa 1996.

Schaefer R., Telega H., Kołodziej J., Stochastic Theory of the Genetic Algorithm, Materials from the Seminar. „Sieci neuronowe, algorytmy genetyczne, zbiory rozmyte”, Rzeszów, 1999.

Stadnicki J., Teoria i praktyka rozwiązywania zadań optymalizacji z przykładami zastosowań technicznych, WNT, Warszawa 2006

Natural lighting in office buildings – energy saving potential in electrical lighting

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ABSTRACT: In a highly luminous climate like the Portuguese, it follows that, in buildings that make large use of electric lighting, like offices, natural light can be used in order to reduce consumption through artificial lighting. However, that does not seem to happen in existent office buildings, older or more recently constructed. This article presents the application of an existent methodology (which determines iluminance levels in interior spaces) to some Portuguese cities, with the intent of measuring the energy savings potential in reducing artificial light use, varying the room's depth and window size. It is concluded that there exists substantial opportunity for reducing artificial lighting electrical consumption, for any considered region in Portugal, although a slightly higher reduction potential exists for southern regions. Moreover, this potential for electrical power consumption can only be achieved if introduced certain measures that manage to control the actual artificial lighting energy as a function of the natural light availability.

1 INTRODUCTION

According to DGE (2002), office buildings consume about 220kWh/m^2, almost exclusively in the form of electricity (lighting, air conditioning and equipment). Lighting needs amount, in average, to about 25% of total energy consumption (Ghisi & Tinker 2005) in air conditioned buildings, reaching 70% in non-conditioned buildings.

Natural light is a vast resource in Portugal, in such a way that the annual horizontal illuminance average exceeds 12600lux, while on the vertical plane it surmounts 6200lux. The reference daily illuminance is 5000lux, which corresponds to the average CIE overcast day (Costa 2003). Average solar time distribution plots are shown (average months between 1960 and 1990), as mere examples, for Lisboa and Bragança (Instituto de Metereologia e Geofísica), in Figures 1-2.

Although natural light use in office spaces must consider important factors as glare and contrast level control (for comfortable work with screens) (Costa, 2003), there is considerable potential for natural light use in those spaces, with substantial electricity demand reduction.

An office lighting system that takes into account natural light distribution can only fully operate if it provides a simple way to, manual or automatically, shut down part of the installed lighting circuit and/or reduce the output of certain lamps, depending on the interior light availability (Choi et al. 2005).

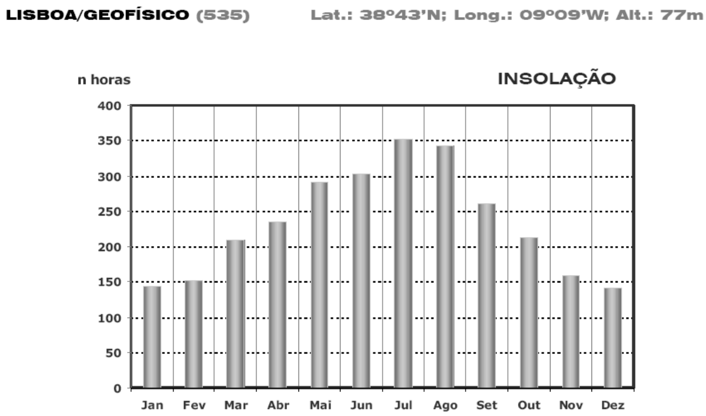

Figure 1. Average solar time distribution in Lisboa (Instituto de Metereologia e Geofísica)

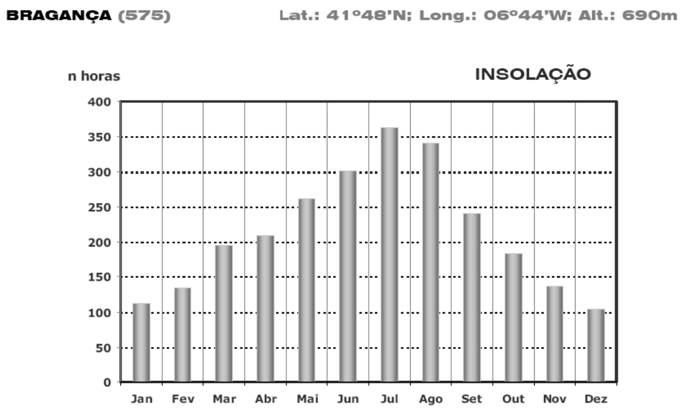

Figure 2. Average solar time distribution in Bragança (Instituto de Metereologia e Geofísica)

2 EXTERIOR ILLUMINANCE

The exterior illuminance depends on several factors: latitude, time of year, time of day, climatic conditions (cloudiness) and measurement angle (captured illuminance is different in the horizontal and vertical planes). Taking the CIE Standard-Sky as reference, the used exterior illuminance levels, in cloudy and sunny days, in both horizontal and vertical planes, are calculated using the following expressions (Costa 2003):

Horizontal illuminance in a cloudy day:

$$E_{xh,n} = 301 + 21013.sen(h_s) \quad \text{(lux)} \tag{1}$$

where h_s is the sun's altitude, in degrees.

Horizontal illuminance in a clear day:

$$E_{xh,l} = 1100 + 15500\sqrt{sen(h_s)} \quad \text{(lux)} \tag{2}$$

Vertical illuminance in a cloudy day:

$$E_{xv,n} = 119 + 8321.sen(h_s) \quad \text{(lux)} \tag{3}$$

Vertical illuminance in a clear day:

$$E_{xv,l} = E_{xh,l} \cdot \left(\frac{R_m}{2} + \alpha \right) \quad \text{(lux)} \tag{4}$$

where R_m is the average exterior pavement reflectance (considered equal to 0,5) and

$$\alpha = \frac{E_{xh,n}}{E_{xv,n}} \quad . \tag{5}$$

Provided the solar angles (sun's altitude) for the Portuguese latitude (which in this study is taken as 38º45' - latitude deviations between northern and southern continental Portuguese locations are considered to have insignificant impact on the results) - Table 1 – and the solar time distribution – Table 2 (in Lisboa) – exterior illuminance values are calculated for the average day – Table 3.

Table 1. Solar angles in Lisboa, latitude = 38º45'N

Time of day, h	Jan.	Feb.	March	April	May	June	July	August	Sep.	October	November	December
6	0	0	0	8	13	15	13	8	0	0	0	0
7	0	0	11	19	24	25	24	19	11	0	0	0
8	8	15	22	30	35	37	35	30	22	15	8	5
9	16	24	33	40	47	50	47	40	33	24	16	15
10	24	31	41	51	58	60	58	51	41	31	24	21
11	29	37	49	59	66	70	66	59	49	37	29	25
12	30	39	50	61	70	84	70	61	50	39	30	26
13	29	37	49	59	66	70	66	59	49	37	29	25
14	24	31	41	51	58	60	58	51	41	31	24	21
15	16	24	33	40	47	50	47	40	33	24	16	15
16	8	15	22	30	35	37	35	30	22	15	8	5
17	0	5	11	19	24	25	24	19	11	5	0	0
18	0	0	0	8	13	15	13	8	0	0	0	0
19	0	0	0	0	3	5	3	0	0	0	0	0

Table 2. Solar time distribution in Lisboa

	Jan.	Feb.	March	April	May	June	July	August	Sep.	October	November	December
Hours	140	150	210	230	290	305	350	340	260	215	160	140

The average day represents a mix between clear and cloudy days, in such a way that it reflects the proportion between clear sky and overcast sky hours, over the time period of a month or of one year. The solar time distribution sets the referred proportion, and since each region has a different solar time distribution, the average day will result in slightly different average illuminance levels.

3 INTERIOR ILLUMINANCE AND SAVING POTENTIALS

Interior illuminance obviously depends on the exterior illuminance and can be calculated through the designated Daylight Factor, defined as the percentage of exterior light that effectively reaches the interior and is diffused in that space. The Daylight Factor method is detailed in standard BS 8206, part II, not being explained further here. This factor also depends on the room's geometry, window size, existing shading devices, working plane height, reflectance of interior surfaces and existence of exterior surfaces.

Table 3. Exterior illuminance values in the vertical plane, in Lisboa

Hour of day	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
6	0	0	0	3012	4386	4666	4689	3842	485	0	0	0
7	0	0	3677	4797	5984	6065	6298	5739	3798	472	406	0
8	2756	3878	5338	6202	7241	7398	7538	7122	5466	4382	2813	2161
9	4071	5137	6663	7259	8324	8514	8591	8115	6786	5649	4136	3921
10	5180	5992	7470	8202	9078	9157	9319	8975	7585	6490	5245	4783
11	5800	6650	8155	8746	9488	9618	9712	9461	8262	7128	5864	5308
12	5918	6855	8232	8863	9650	9954	9866	9565	8339	7325	5982	5434
13	5800	6650	8155	8746	9488	9618	9712	9461	8262	7128	5864	5308
14	5180	5992	7470	8202	9078	9157	9319	8975	7585	6490	5245	4783
15	4071	5137	6663	7259	8324	8514	8591	8115	6786	5649	4136	3921
16	2756	3878	5338	6202	7241	7398	7538	7122	5466	4382	2813	2161
17	395	2127	3677	4797	5984	6065	6298	5739	3798	2530	406	395
18	0	388	464	3012	4386	4666	4689	3842	485	472	0	0
19	0	0	0	443	2244	2757	2457	598	485	0	0	0
20	0	0	0	0	0	520	579	0	0	0	0	0
Average[1], lux	4193	4789	5492	6125	7207	6938	7013	6905	5256	4842	3901	3818
Average in working days[2], lux	4897	5423	6921	7921	9005	9185	9283	8819	7039	5916	4962	4502
Annual average, lux			5577									
Annual average in working days[2], lux			6990									

[1] – Average of daylight hours

[2] – Average of daylight working hours, from 9:00h to 18:00h.

The calculation method divides the room area in a rectangular grid, refined as needed. Considering the parameters referred in the last paragraph, the Daylight Factor in calculated, for each point in the grid. For each region, since the exterior average illuminance is always different (Table 4), then, with all other parameters constant, interior average illuminance is also different for each case (and for each grid point).

Table 4 – Exterior annual average day illuminance in the vertical plane, for four Portuguese cities

City	lux
Bragança	6811
Porto	6756
Lisboa	6990
Faro	7186

In each grid point, the calculated interior illuminance is compared with the minimum interior illuminance level which guarantees good working lighting conditions in an office space. This level, dependent on several factors (working detail, perception of colors, schedules, amongst others), is explained in BS 8206, part 1 (artificial lighting in buildings) and has been considered for this study, in a simplified way, equal to 500lux. Comparing these two illuminance values determines if, in each grid point, there is or not enough natural light to satisfy the minimum illuminance level. If the result is positive, then, at a certain point, artificial light can be shut off; if the result is negative, then artificial light must provide the remaining illuminance quantity to reach 500lux.

In this way, potential energy savings can be calculated for several window sizes and country regions. For a certain room size, the area where the minimum illuminance level is guaranteed by natural light alone, then the saving potential is 100%. In the remaining room area, an averaged sum is performed with the relation between interior and minimum illuminance levels. The final global potential saving is simply the sum of the partial potential savings, referred to the total room area. The following expressions reflect the described concepts, having been used to reach the presented results in the next chapter.

$$P_d = \frac{A_s}{A_a} \times 100 \quad (\%) \tag{6}$$

where P_d is the saving potential associated with shutting down the lights, A_s is the area (in m^2) where this shutting down can occur and A_a is the room's total area (in m^2);

$$P_c = \frac{A_e \sum_{i=1}^{n} 100 \frac{I_i}{I_b}}{A_c} \quad (\%) \tag{7}$$

where P_c is the saving potential associated with the use of natural light in areas where it does not fulfill the minimum requirements, A_e is the mesh element area, I_i is point i interior illuminance, I_b equals the minimum illuminance level (500lux), A_c is the area in which artificial light can be backed up with natural light and n is the number of points which can be counted inside area A_c;

$$P_g = P_d + \left(1 - \frac{P_d}{100}\right) \times P_c \quad (\%) \tag{8}$$

where P_g is the global potential artificial light saving percentage.

4 RESULTS

Based on the method described in the previous chapter, global potential savings where calculated, for different room sizes, window sizes and country regions. Table 5 shows the basic parametric changes implied in the calculations.

Other possible variables have been fixed, for simplicity, namely interior surface reflectance (80% for opaque surfaces and 15% for the window glass), room's width (3m), window type (clear double glass with a PVC frame), room's condition (clean) and type of work performed (clean).

Table 5. Parametric variations chosen for the global savings potential calculation

Parameter	Variation			
Depth (m)	3	4	5	6
Window size, A_w (m^2)	1	2,25	4	6,25
Region	Bragança	Porto	Lisboa	Faro

Partial results are shown for Lisboa (Figs 3-5) and global ones for the considered regions (Figs 6, 7), for rooms with depths of 3 and 6m. Table 6 depicts all global potential savings results, for all regions, window sizes and room depths.

It is clear that each of the calculated potential savings decreases as room depth increases or window size is shrunk. However, window size has much greater impact on potential savings than room depth (Figs 3-5). On the other hand, a complete energy consumption analysis on a typical office room does not rest at lighting considerations, also involving thermal aspects, both in summer and winter. Considering this, window size optimization will have to minimize global energy consumption, taking into account heating, cooling and lighting loads (Ghisi & Tinker 2005).

A slight increase in the global savings potential is also observed, with increasing exterior average illuminance. This relatively small impact can be explained, however, by the fact that, even in overcast days, the exterior illuminance in the vertical plane is about 10 times as great as the interior minimum need (500lux). On the other hand, the illuminance values refer to diffuse light (sky, exterior and interior reflection components) and not to direct sunlight. The latter is not, generally, welcomed in working environments, since it can generate inconvenient glare, reduces the necessary contrast in working with computer screens and degrades interior surface colors.

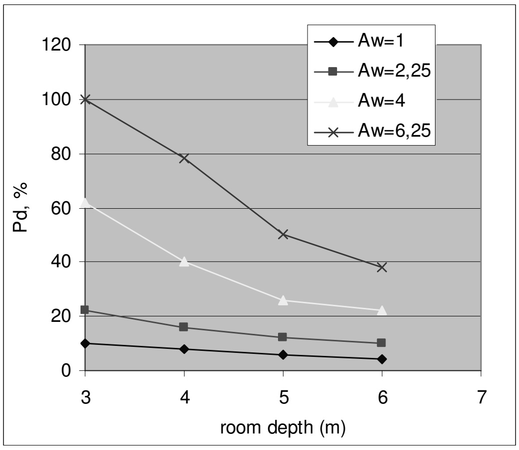

Figure 3. Variation in the potential savings induced by light shut off, in Lisboa

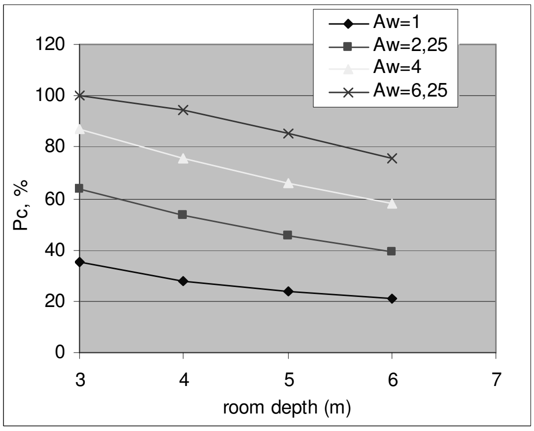

Figure 4. Variation in the potential savings where artificial light can be backed up by natural light, Lisboa

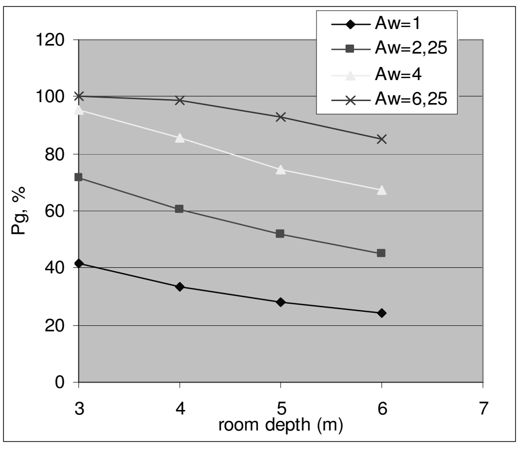

Figure 5. Variation of global savings potential, in Lisboa

It is also worth noting that decreasing interior illuminance due to room depth can be partially offset with the introduction of reflective light shelves, flat or parabolic, as well as enhancing the interior reflectance room properties (Ochoa & Capeluto, 2006).

5 CONCLUSIONS

Lack of natural lighting in office buildings is still a reality in Portugal, although its solar light availability is large. This generous natural light incidence is traduced by exterior illuminances for the average day (working hours, in a mixture of clear and overcast days) that range between 6750 and 7190lux, for the vertical plane, reaching 12700lux in the horizontal plane (in Faro), values that are substantially higher than the standard overcast illuminance, 5000lux.

This way it is possible, if precautions are taken to avoid glare and lack of contrast, to reduce electricity consumption considerably in office lighting, by simply taking into account natural lighting in design and operation of lighting systems for offices.

The calculated global potential savings (for the Portuguese cities Bragança, Porto, Lisboa and Faro) range between 26 and 100%, even though it is noticeable that, for window areas greater than $4m^2$, in any of the considered cities and for any depth (in this case, up to 6m), the savings are always over 65% (Table 6). The saving potentials are, naturally, linked with the exterior illuminance during the diurnal working period (or, more rigorously, to the average exterior illuminance within the working period, averaged throughout the year), when it is actually possible to benefit from natural light, which excludes, obviously, night hours.

Since it is rather clear the potential for natural light use in designing and use of office spaces, it is very important to introduce measures, both in new building construction and retrofits, which minimize electricity consumption in lighting, assuring simultaneously minimum interior illuminance levels. These measures might simply involve separating lamp circuits (allowing, for instance, turning off lamp groups, by sections, according to their distance from the exterior windows) or installing more complex lamp flux control, through light sensors and electronic ballasts.

Table 6. Global potential savings for the considered regions and parametric variations in window area (m^2) and room depth (m)

Window area, m2	Bragança	Porto	Lisboa	Faro	Room depth, m
1	40,84	40,59	41,65	42,54	3
	32,95	32,75	33,61	34,33	4
	27,69	27,51	28,26	28,88	5
	23,83	23,67	24,35	24,92	6
2,25	70,55	70,16	71,83	73,22	3
	59,54	59,18	60,68	61,93	4
	50,79	50,47	51,81	52,92	5
	44,30	44,02	45,20	46,19	6
4	94,16	93,86	95,09	96,02	3
	84,21	83,82	85,43	86,71	4
	73,39	73,01	74,64	75,99	5
	66,10	65,75	67,26	68,51	6
6,25	100,00	100,00	100,00	100,00	3
	98,24	98,08	98,77	99,31	4
	91,68	91,33	92,78	93,97	5
	83,79	83,40	85,01	86,33	6

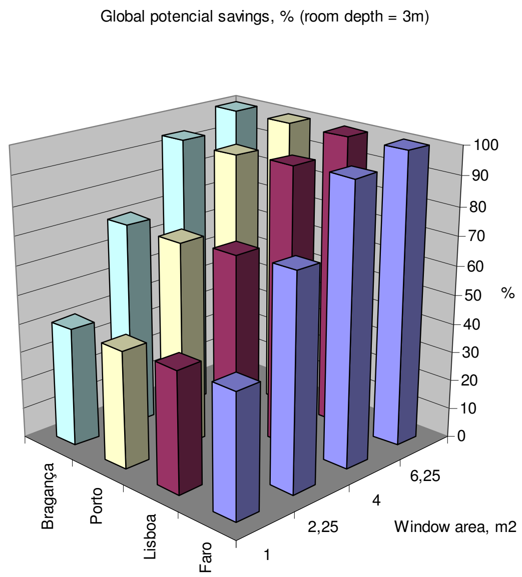

Figure 6. Global potential savings for a 3m depth room

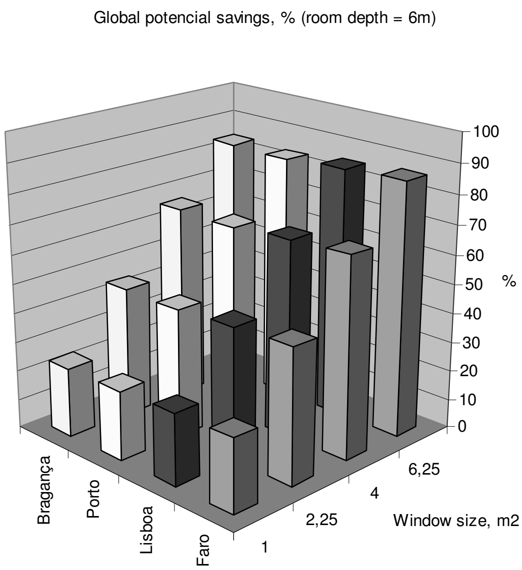

Figure 7. Global potential savings for a 6m depth room

REFERENCES

British Standard BS 8206, part II – daylighting.

Choi, An-Seop; Song, Kyoo-Dong & Kim, Yong-Shik 2005. The characteristics of photosensors and electronic dimming ballasts in daylight responsive dimming systems. *Building & Environment* 40: 39-50.

Direcção Geral da Energia (DGE) 2002. *Building's energy efficiency* – Lisboa: Economy Ministry (in Portuguese).

Instituto de Metereologia e Geofísica 2007. *Climate Averages 1961-1990*. Available at http://www.meteo.pt/pt/clima/info_clima/clima_normais.jsp (in Portuguese).

Ochoa, C.E. & Capeluto, I.G. 2006. Evaluating visual confort and performance of three natural lighting systems for deep office buildings in highly luminous climates. *Building & Environment* 41: 1128-1135.

Santos, A.J.Costa 2003. Development of an *in situ natural lighting* characterization methodology. Masters thesis. Lisboa: LNEC (in Portuguese).

Tinker, John A. & Ghisi, E, 2005. An ideal window area concept for energy efficient integration of daylight and artificial light in buildings. *Building & Environment* 50: 51-61.

Gypsum plasters for energy conservation

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ABSTRACT: Energy conservation in buildings, through materials thermal storage, is relatively low relying only on sensible heat. There are however other materials, phase change materials (PCM), that have been incorporated in buildings as an effective solution both for more efficient use of energy and its consumption reduction, allowing the use of free energy in the environment, by latent heat storage, and so regulating thermal comfort parameters inside buildings.

This paper presents part of the ADI/2006/V4.1/0035, "GESREV – Development of new integrated system, based in gypsum, for interior plastering of construction systems" research project, financed by IDEIA – POCI 2010 Program. The objective to develop based on an existing technique, a new finishing gypsum plaster with thermal enhanced properties, namely latent heat storage capacity, by incorporating microencapsulated phase change materials. With the experimental work done so far, plaster composition was developed in order to fulfill the mechanical properties standard requirements, while thermal performance in Passys test cells is being carried.

1 INTRODUCTION

In Portugal residential buildings account for 20% of the final energy consumption, 25% of which is used for space heating and cooling. Despite over 20% of the buildings have less than 10 years, around 60% were built before 1990, not fulfilling energy efficiency regulations. Therefore much of the above mentioned energy is wasted both due to inefficient thermal insulation and lack of thermal energy storage systems (passive or active).

Thermal storage through materials is based on two important properties: sensible heat and latent heat, with the later much greater than the first. For instance, comparison between the sensible heat capacity of concrete (1.0 kJ/kg.ºC) with the latent heat of a phase change material (PCM), such as a technical grade paraffin as octadecane (205 kJ/kg with a melting range temperature between 22.5-26 ºC), shows significant difference between both properties.

In lightweight constructions, Trombe walls are used for direct solar gains. In typical Portuguese buildings high thermal mass masonry is used, making it suitable for passive solar applications. Nevertheless most buildings still present interior temperatures above comfort limits in summer and below in winter. Another problem is the variation on energy net demand, leading to differential pricing system for peak and off-peak periods.

Interior walls offer large areas for passive heat transfer. As the interior lining is usually made with multilayer gypsum plaster, in which the finishing layer is very thin, phase change materials can be easily added to the plaster and installed, both in new constructions and during rehabilitation processes with no additional cost, except for the material. Introducing latent heat thermal energy storage, contributes to stabilize the internal environment, improving thermal comfort by storing either heat or cool and releasing it in periods when the demand is higher, this way minimising energy consumptions.

2 PHASE CHANGE MATERIALS (PCM)

Organic and inorganic compounds are the two most common groups of PCM. Organic PCM are divided in paraffins and non-paraffins, while inorganic PCM are divided in salt hydrates and metallics. There are also eutectics which are a minimum melting composition of two or more components. Some of the materials used as PCM and their properties are shown in Table 1.

Before selecting the appropriate PCM several characteristics should be considered: range of melting and freezing required; high latent heat of transition, thermal conductivity and specific heat; density; little or no subcooling during freezing; chemical stability; melting/freezing point congruency; low vapour pressure at room temperature; small transition volume change as well as renewable vegetable and animal sources of supply.

Commercial paraffin waxes are cheap, have moderate thermal storage densities (200 kJ/kg or 150 MJ/m^3), present a wide range of melting temperatures, negligible subcooling, no phase segregation and are chemically inert and stable, however they present low thermal conductivities (0.2 W/m.ºC).

Hydrated salts present high volumetric storage density (350 MJ/m^3) when compared to paraffins, relatively high thermal conductivity (0.5 W/m.ºC) and moderate costs, however due to phase segregation and subcooling their application is limited. Because they melt congruently, storage density decreases with thermal cycling.

Table 1. PCM and their properties (Tyagi et al. 2005 and Kelly 2000).

Compound	Melting Point (ºC)	Heat of Fusion (kJ/kg)
$KF.4H_2O$	18,5	231
$CaCl_2.6H_2O$	29	190
$Na_2SO_4.10H_2O$	32	251
$LiNO_3.3H_2O$	30	296
$Zn(NO_3.)_2.6H_2O$	36,4	147
Butyl stereate	19	140
1-dodecanol	26	200
45/55 Capric-lauric acid	21	143
Propyl palmitate	19	186
1-tetradecanol	38	205
66,6% $CaCl_2.6H_2O$ / 33,3% $MgCl_2.6H_2O$	25	127
47% $Ca(NO_3)_2.4H_2O$ / 53% $Mg(NO_3)_2$.6H2O	30	136
60% $Na(CH_3COO).3H_2O$ / 40% $CO(NH_2)_2$	30	200

Energy stored in a PCM product depends on the melt temperature range of the PCM and on the latent capacity per unit area of the product. The melting temperature range should be chosen, based on the objective of its application, whether is to save energy during cooling or heating.

Over the years different techniques to integrate PCM into the building materials have been studied. These techniques included mainly immersion and encapsulation.

In the immersion process the porous building material is dipped into the hot melt PCM, which is absorbed by capillarity. This is easy to perform but PCM may interact with the structure, changing the properties of the materials matrix by reacting with it or by leakage.

Encapsulation of the PCM in tubes, pouches, spheres or panels is an effective way of containing the material, however, macro-capsules heat transfer rates decrease due to low heat transfer coefficients during freezing, preventing the system to fully discharge. More, this method requires protection of the containers from destruction during integration.

Micro-encapsulation allows easy integration of the PCM into conventional porous materials, preventing the interaction of the PCM with the matrix, good stability and larger heat transfer surface, affecting however mechanical strength of the elements.

For wallboards for example, direct incorporation at the mixing stage is preferred because little additional process equipment and labour is required, however, if no contention mechanisms are used, leakage may be a problem. Nevertheless, PCM wallboard and conventional wallboard characteristics present flexural comparable strengths, around 15% difference in thermal conductivities depending on the PCM used and its amount and excellent fire resistance. For radiant floor applications shape-stabilized PCM plates are most common.

Major concerns with safety codes and flammability requirements imposed to construction materials lead to the development of techniques to prevent fire hazards. Adding fire retardants in materials composition is usually an effective measure. Examples include, non-flammable surface materials such aluminium foil or rigid PVC film for plasterboards and brominated hexadecane and octadecane combined with antimony oxide for other applications, since it self extinguishes.

3 THERMAL STORAGE MATERIALS PERFORMANCE

The incorporation of PCM in different materials for several applications has been studied. Due to widespread application, most of these researches focus on wallboards, concrete blocks and shape stabilized PCM plates for radiant under floor heating.

Peippo et al. (1991) showed that a house with 120 m^2 in Madison, Wisconsin (43ºN), could save up to 4 GJ a year (or 15% of the annual energy cost). They have also concluded that the optimal diurnal heat storage occurs with a melt temperature 1–3 ºC above average room temperature.

Feldman et al. (1995) studied the performance of gypsum wallboard, for cooling storage at night, impregnated by immersion with 22-25%-wt (2 kg/m^2) PCM with a melting range of 22-26 ºC. Wallboard presented good stability with thermal properties remaining unchanged after cycling. Researchers concluded that within a temperature interval of 3.5 ºC, the total storage capacity of the PCM wallboard was 381 kJ/kg, which was 12 times higher than the storage capacity of the wallboard alone.

Thermal performance of a full-scale outdoor test room with inside lining made of gypsum wallboard containing 25%-wt. PCM, with a temperature transition range of 16-21 ºC, was investigated by Athienitis et al. (1997). Results showed a maximum temperature of 21 ºC registered in the wallboard containing PCM against 27 ºC in regular wallboard. Freezing process was observed to last up to 7-11 hours. With a total wallboard area of 20 m^2, a 10 MJ increase in heat transfer was measured, corresponding to approximately 15% of the total heat load

The thermal dynamics of gypsum-PCM wallboard not directly illuminated by sunlight were studied by Neeper (2000). In this study daily variation of room temperature was between 20 ºC and 26ºC with an average around 21.5 ºC. The wallboard was 12.7 mm thick, containing 10% and 20% PCM, with a latent heat capacity of 192 kJ/m^2 and 427 kJ/m^2 respectively. From he's studies Neeper concluded that a design value for wallboard energy storage was in the range of 300-400 kJ/m^2, which is very important data when calculating heating or cooling needs.

Another wallboard thermal performance study was carried by Kissock et al. (1998). The wallboard was imbibed with 30-wt% with commercial paraffin PCM (K18). In the simulations conducted, solar radiation, ambient temperature and interior temperatures in the test cells were continuously monitored for 14 days. Results indicated that peak temperature in the phase change test cell were up to 10 ºC less than in the control test cell during sunny days.

A combined system for space heating and hot water was investigated by Ip (2000). Water heated by a solar panel is used to charge the PCM of an under floor panel, through which the mat of water tubes circulate. Considering a solar radiation of 9.8 MJ/m^2 with a total system efficiency of 25%-50%, applied in a two storey 3 bedroom house with 100 m^2, a heating load of 1.6 MJ/m^2 and a collector with 6 m^2, Ip estimated energy savings of around 6%-12.5%.

More recently Schossig et al. (2004) studied the behaviour of PCM gypsum plaster in full-size lightweight test rooms. Gypsum plasterboard was mounted on wooden slats with 14 cm thick polyurethane foam insulation. Two different gypsum plasters were used: a 40 %-wt. PCM 6 mm thick and a 20 %-wt. PCM 15 mm thick. The PCM melting temperature range was 24-27 ºC.

Results of this experiment demonstrated that, for the 6 mm plaster, maximum room temperature with PCM was reached 1 hour later and was 4 ºC lower. More, during three weeks, the reference room temperature was above 28 ºC during 50 hours while in the PCM test room was only around 5 hours. One important feature of this work was the use of Venetian blinds and night ventilation to achieve full discharge of the PCM.

Gypsum plasters incorporating PCM have also been study and investigate in Minho University, in order to develop a new multilayer plastering system. Commercial gypsum plaster (Monteiro, 2005) has been mixed with 25%-wt. micro-encapsulated PCM with a melting temperature around 20 ºC, by direct incorporation and compared with the same conventional plaster. Figures 1 and 2 present some of the results achieved.

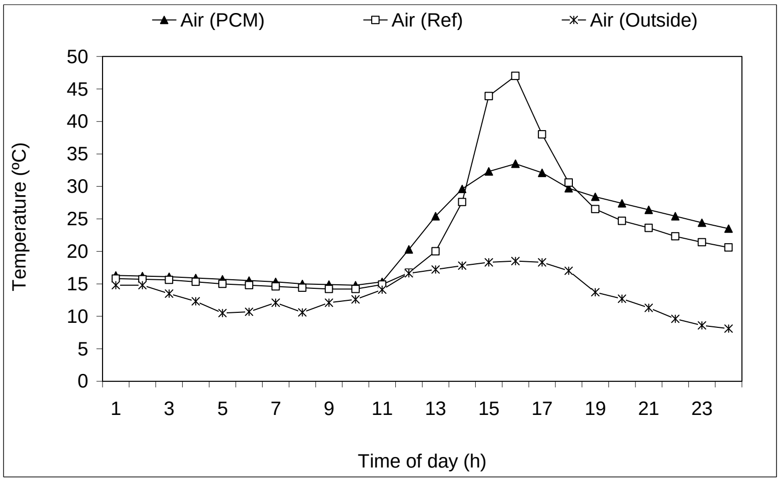

Figure 1. Air temperature profiles for the two test rooms in the hottest day (Monteiro, 2005).

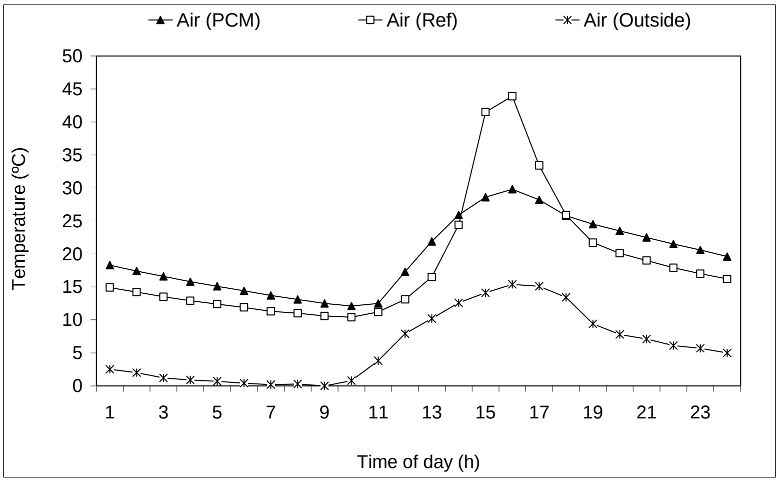

Figure 2. Air temperature profiles for the two test rooms in the coldest day (Monteiro, 2005).

Results, obtained during winter, indicate a reduction of 29% in the maximum temperature for the hottest day, while in the coldest this reduction was of 32%. For the minimum temperature increases of 4% and 14% in the hottest and in the coldest day, respectively, were observed.

These results led to conclude that PCM with a melting range around 20 ºC are suitable for thermal performance in winter, when heating loads are higher, effectively regulating interior thermal comfort parameters.

One of the drawbacks of Monteiro's work, was the non conformity of the gypsum plaster with the requirements of the new EN 13279-1 (CEN 2005), namely, in what concerns to mechanical properties of the gypsum-PCM mortar. This new European standard (CEN 2005) sets at least 1 MPa for flexural strength and 2 MPa for compressive strength.

4 EXPERIMENTAL WORK

The first part of the experimental work consisted in the development and evaluation of the gypsum mortars mechanical properties (flexural, compressive and adhesive strengths), while the second consists in the comparison between the thermal performances of two rooms plastered with and without PCM. The final goal is to predict the amount of energy that can be saved by incorporating the PCM, while maintaining comfort parameters in the room.

Three different compositions (F3, F4 and F5) of finishing layer gypsum plaster, in which 25%-wt. PCM was directly incorporated at the time of mixture, were evaluated. The amount of PCM incorporated was defined, based in the mentioned references and in preliminary mechanical tests (Silva et al. 2006). The PCM, a technical grade hexadecane paraffin wax, microencapsulated in a melamine-formaldehyde resin, with an average particle size distribution of 20-30 µm, presented a melting temperature around 20 ºC and a latent heat of fusion of 140 kJ/kg.

Flexural and compressive tests were carried in 40 x 40 x 160 mm^3 specimens while adhesive strengths were tested directly in plastered pilot scale brick walls, according with EN 13279-2 standard (CEN 2004).

5 RESULTS

Figures 3 and 4 present the results obtained for mechanical properties testing carried, in order to select the appropriate finishing plaster for thermal testing.

The analysis of the experimental results led to conclude that the incorporation of PCM in the mortar reduces significantly the mechanical properties of the final plaster. Nevertheless, through the research work carried out the tree different compositions could be established, in order to fulfil the requirements of standard EN 13279-1 (CEN 2005).

It was also concluded that the ideal mixing water content, both for workability and mechanical properties is around 70% for the other three (F3, F4 and F5). The EN 13279-1 doesn’t set any requirement standard for adhesion between plaster layers in test walls, this property showed good results, both with and without paint, despite the different fracture patterns.

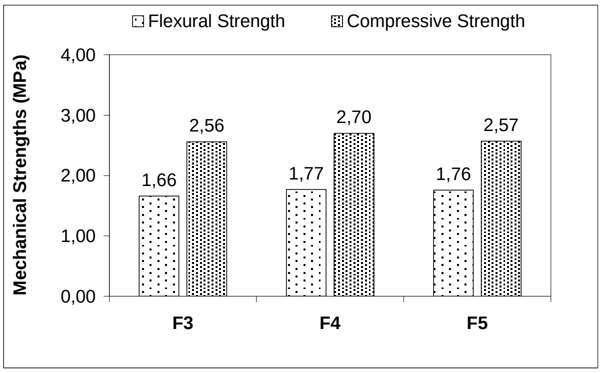

Figure 3. Mechanical properties of modified compositions incorporating 25% PCM.

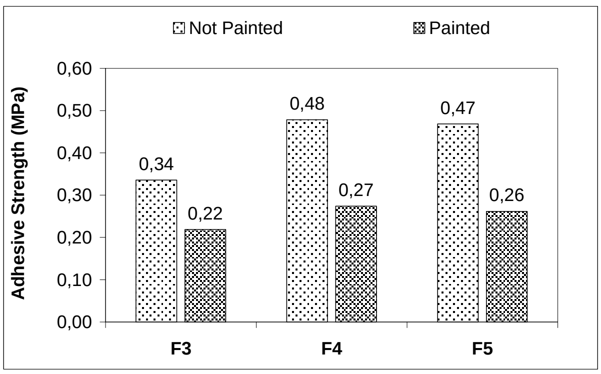

Figure 4. Adhesive strengths of modified compositions incorporating 25% PCM.

6 CONCLUSIONS

The incorporation of PCM in buildings is an effective way of improving thermal performance by energy storage in construction elements. It can be used for passive solar heating by integrating mainly the walls, maximizing solar radiation gains, in active heating systems combined with solar collectors or electricity through radiant floor and also in cooling systems with night ventilation.

Studies have demonstrated that PCM can contribute to minimize temperature fluctuations inside buildings, regulating thermal comfort parameters, while shifting heating or cooling peak loads to off peak electricity periods.

In order to compare the performance in terms of energy consumption and heat fluxes of two rooms, one containing a PCM material and the other the conventional material, identical temperature histories must be established. Careful experimental design is required to demonstrate quantitative energy savings and to emulate buildings performance; glazing and temperature history, insulation and ventilation should be similar to the real building.

REFERENCES

Athienitis, A.K., Liu, C., Hawes D.W., Banu D. & Feldman D. 1997. Investigation of the thermal performance of a passive solar test-room with wall latent heat storage. *Building and Environment*, 32(5):405-410.

CEN. 2005. EN 13279-1, Gypsum binders and gypsum plasters – Part 1: Definitions and requirements, *European Committee for Standardization*, Brussels, Belgium.

CEN. 2004. EN 13279-2, Gypsum binders and gypsum plasters – Part 2: Test methods, *European Committee for Standardization*, Brussels, Belgium.

Feldman, D., Hawes D.W. & Banu D. 1995. Development and application of organic phase change mixtures in thermal storage gypsum wallboard. *Solar Energy Materials & Solar Cells* 36:147–157.

Ip, K.C.W. & Gates, J.R. 2000. Thermal storage for sustainable dwellings. *International Conference Sustainable Building 2000*, 22-25 October, Maastricht, The Netherlands.

Kelly, R. 2000. Latent Heat Storage in Building Materials. *AMEC Design.*

Kissock J.K., Hannig J.M., Whitney T.I. & Drake M.L. 1998. Testing and simulation of phase change wallboard for thermal storage in buildings. *Proceedings of 1998 International Solar Energy Conference*, p.45–52, New York, USA.

Lee T., Hawes D.W., Banu D. & Feldman D. 2000. Control aspects of latent heat storage and recovery in concrete. *Solar Energy Materials & Solar Cells* 62:217–237.

Monteiro, J. 2005. The Use of Active Materials for Thermal Performance Improvement of Constructive Systems, *Thesis of Master of Science in Civil Engineering, University of Minho, Guimarães, Portugal,* (in Portuguese).

Neeper, D.A. 2000. Thermal dynamics of wallboard with latent heat storage. *Solar Energy,* 68(5):393–403.

Peippo K., Kauranen P. & Lund P.D. 1991. A multi-component PCM wall optimized for passive solar heating. *Energy & Buildings* 17:259–270.

Schossig, P., Henning, H.-M., Gschwander, S. & Haussmann, T. 2005. Micro-encapsulated phase-change materials integrated into construction materials. *Solar Energy Materials & Solar Cells* 89:297–306.

Silva, N., Aguiar, J.B., Bragança, L.M., Freire, T. & Cardoso, I. 2007. Properties of gypsum-pcm based mortars for interior plastering of construction systems. *Proceedings of Materiais 2007 – 13th Conference of Sociedade Portuguesa de Materiais / IV International Materials Symposium*, Part II, p.702, 1-4 April, Porto, Portugal.

Tyagi, V.V. & Buddhi, D. 2005. PCM Thermal Storage in Buildings: A State of Art. *Renewable and Sustainable Energy Reviews*. (Article in Press).

Implementing the low energy concept into current Irish housing building delivery processes – issues and barriers

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ABSTRACT: This paper describes the additional considerations in the practice of building a low energy dwelling compared to building a typical dwelling built to current building regulation energy standard in Ireland. It highlights issues, that are specific to a low energy dwelling within planning, design, construction and post construction stages, being addressed for their achievement. There is a lack of knowledge in the design low energy dwellings; lack of know how on site practices required to achieve low levels of air tightness and good quality installation of building systems. In the post construction phase undertaking a pressurization test and achieving low air tightness level is not required in main stream construction, resulting in a lack of knowledge, available equipment, and additional costs associated with it. This paper concludes by discussing areas where improvements are necessary to overcome barriers to successfully implement the low energy concept within Irish building delivery processes.

1 INTRODUCTION

1.1 *Irish Residential Building Construction Sector*

The residential building market in Ireland has seen unprecedented levels of construction over the last ten years. Since 1994 the number of dwellings constructed each year in Ireland has increased by over 300%, with a record number of 80,957 dwellings constructed in 2005, and 66,470 housing units completed nationally within the first nine months of 2006 (DOEHLG 2006). With such a buoyant building construction market it is not surprising that in 2005 the residential sector accounted for total final energy consumption of 2,874 kilo tonnes of oil equivalent (ktoe) of Ireland's total energy consumption (SEI 2005). Even more, the residential sector is the second largest consumer of energy for 2005 after the transport sector and higher than the individual energy consumption of the industry, commercial / public services and agriculture sectors (SEI 2006). Looking at the energy consumption of the residential sector, over half of this energy was due to the level of space heating required in the maritime climate.

The typical energy use breakdown of a new build dwelling, built to current building energy regulation standard in Ireland is: space heating 97 kWh/m2.y; DHW heating 33 kWh/m2.y; electricity use for appliances 28 kWh/m2.y amounting to total electricity use 49 kWh/m2.y. The total delivered energy is therefore 179kWh/m2.yr. Compared to a low energy building construction standard, for example the Passive House standard, where the total energy demand for space heating is limited to 15 kWh/m2.y. it is in fact a considerable reduction of 84% in space heating, as shown on Figure 1.

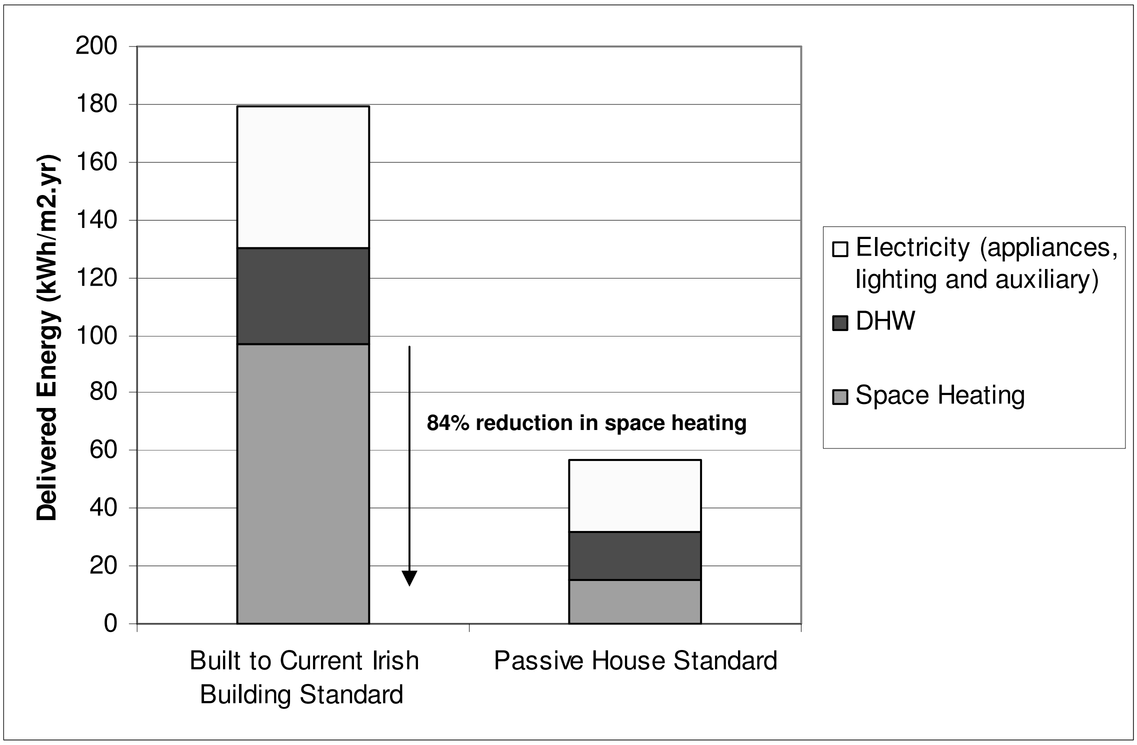

Figure 1. Delivered energy in Irish Housing built to current building regulation standard compared to Passive House standard.

** Figure 1 assumed: 50% of DHW in the Passive House is supplied by solar thermal source and the space heating source is non electric based.*

The term Passive House (*Passivhaus* in German) refers to the rigorous standard for energy use in buildings resulting in buildings that require little energy for space heating. Despite the name, the standard is not confined only to houses. Several office buildings, schools, etc. have also been constructed to the standard. Although it is mostly applied to new buildings, it has also been used for refurbishments. The first Passivhaus buildings were built in Darmstadt, Germany, in 1990. Since then, more than 6,000 Passivhaus buildings have been constructed in Europe, most of them in Germany and Austria, with others in various countries world wide.

If one looks at the fuel type mainly used for space heating in Ireland it is oil or increasingly natural gas where available, fired boiler with water as heating fluid to high temperature radiator panels and hot water cylinder (also supplying DHW). The significance of these figures is highlighted by the fact that Ireland's greenhouse gas emissions were 23.5% greater than 1990 levels in 2004 despite a Kyoto Protocol target of +13% between 2008-2012 (EPA 2006). With the EU Energy Performance of Buildings Directive, EPBD due for implementation between 2006 and 2009 the awareness of building energy performance will increase substantially.

Mandatory building regulations concerning the conservation of fuel and energy in dwellings, Technical Guidance Document - Part L (TGD Part L) were first introduced to Ireland in 1991, were amended in 1997 and again in 2002 and 2005. The TGD Part L focuses on reducing energy consumption primarily by reducing required U-values, increasing insulation levels and minimizing thermal bridging. However, there is a significant gap in building energy related requirements between TGD Part L and low energy building construction standards, such as Passive House standard. Not only are Passive House minimum U-values for ground floor, wall, roof and windows significantly less than TGD Part L, but Passive House standards go much further by setting requirements for air tightness, passive solar gains and heat recovery whereas Irish regulations do not. The following section highlights areas where these standards differ.

1.2 *Current Irish Building Regulation Standard compared to Low Energy (Passive House) Building Standard*

The opaque elements of the building fabric in current Irish building regulations require maximum thermal transmittance of U ≤ 0.16 W/m2K insulation in roof, U ≤ 0.25W/m2K insulation in floor and U ≤ 0.27W/m2K insulation in external wall. The limit for thermal transmittance through opaque elements of the building fabric in Passive House standard is limited to 0.15W/m2K. Similarly, for glazing the limits are U ≤ 2.2W/m2K in TGD Part L compares to much lower in Passive House standard U ≤ 0.8W/m2K. Infiltration heat losses also show great difference in requirements, the Passive House standard aims at reducing unwanted infiltration (air-tightness testing required) to maximum n50<0.6 ach. On the other hand, in the TGD Part L of Irish Building Regulations no specific air-tightness pressurisation tests are required. Recent study has shown an average air permeability of 28 sample dwellings constructed between 1997-2002, of 11.8m3/hr/m2 @ 50Pa, which is 69% higher than a Good Practice benchmark of 7.0,3/hr/m2@50Pa (Shanks at al. 2006).

Ventilation is another aspect where the two building standards greatly differ. The Passive House standard specifies controlled ventilation with highly efficient mechanical ventilation system with heat recovery (efficiency ≥ 75%), while the Irish regulations recommends values for background ventilation and mechanical extract ventilation (mandatory) in kitchen, bathrooms and utility rooms. Minimising thermal bridging in the Passive House standard is seen as essential to achieving a low energy dwelling. The Irish TDG Part L regulations does specify maximum values of linear thermal transmittance for various building elements junctions. However, these limits range between linear heat coefficient (W/mK) 0.06 up to 0.50, which is much higher than the 0.01W/mK requirement in the Passive House standard.

Overall one could conclude that the Passive House standard goes much further than current Irish Building Regulations by setting specific requirements in order to minimise heat losses through the building envelope, infiltration and ventilation. In addition, the Passive House standard relies on the use of incidental gains, passive solar gains and use of on-site renewable energy to meet the resulting energy demand.

1.3 *Energy Saving Potential from switching to building Low Energy Dwellings*

Recent research undertaken by the UCD ERG on the effect of applying the Passive House standard to new built dwellings indicated that potential savings of 34.5 TWh of energy for space heating and 251.0 $MtCO_2$ emissions could be achieved if 50% of new build residential construction projected for the next 20 years in Ireland was constructed to the Passive House standard (Kondratenko et al, 2006).

Using the calculation model it was found that a typical Irish dwelling, constructed to current building regulations standard, consumes 9,722 kWh/year of delivered energy on space heating and as a result releases 2,855 $kgCO_2$/year into the atmosphere. The space heating requirements for the same size of dwelling built to Passive House standard was found to be only 1,500 kWh/year of delivered energy which equates to 176 $kgCO_2$/year. The difference in delivered energy consumption and carbon dioxide emissions between the two construction types for a single dwelling over one year was therefore 8,222 kWh/year and 2,680 $kgCO_2$/year.

Although in recent years Ireland has tightened up its regulations concerning dwelling energy performance, the results presented above indicate that substantially greater savings are achievable in this area. In striving to meet Irelands Kyoto Protocol commitment and in implementing the EPBD, an ideal opportunity exists for the application of low energy concepts to the way dwellings are designed and constructed in Ireland.

2 IMPLEMENTING THE LOW-ENERGY CONCEPT

2.1 *Issues to be addressed in delivery of Low Energy dwelling in Ireland*

Given the evidence of the benefits of Passive house Standard application the reasons for the current lack of penetration of the low energy building concepts in Ireland need to be addressed. The following section outlines the process of building a low energy dwelling in Ireland.

2.1.1 *Design Phase*

Designing a dwelling begins with a housing developer / owner commissioning an architect to design a low energy dwelling. The architect prepares design drawings, which are submitted to the Planning Authority for Planning Approval. The Planning Authority looks at the Local Development Plan and if the application is in accordance with its planning requirements, and if no appeal to it, Planning Permission for the development is granted. The Architect can start with developing Building Drawings. As part of the process of compliance with building regulations, since 1st July 2006, DEAP or the Dwellings Energy Assessment Procedure, calculations must be prepared. (DEAP was developed by the Irish Government by Sustainable Energy Ireland in response to the European Directive on the EPBD. Part L, Conservation of Fuel and Energy, of the Building Regulations requires DEAP assessments of the energy performance of design of new dwellings, as part of the process of demonstrating compliance.) From 1st January 2007, certified DEAP assessments of the energy performance of all new dwellings will also be required as part of the implementation of the EPBD in Ireland.

All of the above does not differ from the process of designing a typical 'business as usual' dwelling. However, achieving a high standard of energy-efficiency in a building requires more effort in planning and design phases, and also in the construction phase compared to standard construction. Integrated and high quality design processes assist in achieving the desired outcome.

The building envelope of a low energy dwelling is well insulated and air tight. The required minimised thermal bridging and building air tightness represent a very high level of design and construction. The air tightness is extremely important not only to achieve low energy consumption but also in respect to moisture convection and condensation. It is important to prevent humid indoor air penetrating into a highly insulated structure and causing interstitial condensation and creating a potential moisture problem. This is particularly important in Maritime climates such as Ireland, which has high moisture levels in the air. High quality design and construction therefore have a major role.

2.1.2 *Construction Phase*

Following the Tender Phase, contractors are appointed to construct the dwelling. The Building Control in Ireland has a target of 15% for inspection of new built dwellings. In 2005, over 80,000 new dwellings were built in Ireland. In terms of building low energy dwellings the on-site practices and know how are very important in achieving the required air tightness, proper installation of insulation, windows, ventilation system, etc. Achieving the low energy target requires much more rigorous construction process, emphasizing the gap with typical current building practices in Ireland.

The most important phases of the low energy dwelling construction are insulation installation and placing the air tightness layer. Thermal insulation must fill a cavity completely, or lay tight against supporting or load bearing structures. There should not be any air voids in the insulation layer. This requires right dimensions for insulation material and load bearing structures. Insulation should be continuous and thermal bridging is minimised. If a cavity wall construction is used then the insulation should fill the full cavity space, where the insulation is installed by specialists after the wall structure is built. In Ireland full fill cavity when using bricks as an externally cladding in walls is not permitted (!). An air cavity of minimum 40mm or wider is mandatory. This is to provide sufficient ventilation of the structure. Having such regulation does bring the question weather an air tight construction is achievable in this type of construction, emphasizing the importance of appropriate selection of construction technology as well as quality of on-site practices in achieving low energy construction.

2.1.3 *Building Commissioning*

When building a dwelling in accordance to the energy requirements of a Passive House Standard, an air-tightness test is undertaken to confirm that the specific air tightness requirement has been achieved. Infra red camera could be also used for checking the correct placement of insulation and avoidance of thermal bridging. At present in Ireland, no air tightness testing is required by building energy regulations. Also, the use of infra red camera is not wide spread mainly due to cost associated with such tests.

3 BARRIERS TO BUILDING LOW ENERGY DWELLINGS IN IRELAND

3.1 *External Building Envelope*

The thermal envelope of low energy dwelling has the most significant impact on minimising its energy requirements. High level of insulation and optimised air tightness minimise heat loss through the envelope. The value range for thermal transmittance could be as low as 0.06W/m2K up to around 0.15W/m2K or somewhat higher in Maritime climate.

Barriers with respect to insulation of the building envelope in Ireland include building tradition, availability of components and existing building regulations. The tradition of cavity wall construction poses a challenge. To meet the increased insulation requirements attention must be paid to good detailing, selection of appropriately dimensioned items (such as wall ties), and improvements on site practices.

Another barrier is achieving thermal bridge-free construction. The linear thermal conductivity should be significantly reduced in comparison with typical construction practices. Attention must be paid to correct detailing and execution thereof, especially around junctions with window and doorframes, floors, and roofs, foundation walls, etc. There is a lack of know how amongst architects and builders in designing and constructing bridge-free junctions. Design guidelines, construction details examples and on-site good practice must therefore become available.

As with thermal bridge-free construction and good insulation, there are many different areas of construction to be made airtight to reach complete air tightness, dependant on the type of construction and elements applied. For example, to achieve air tightness as low as in the Passive House Standard of n50 value 0.6ac/h, attention to design construction details and to site workmanship as well as sourcing appropriate materials, tapes and adhesives is essential. In Ireland, barriers in achieving this include a lack of construction skills and workmanship and on site quality control. Training material for contractors and improvement in contractor skills is much needed.

Imports have led to a penetration of low energy and well insulated windows and doors in the market. Although these components are now available, they are generally more expensive. As demand increases, however, it is expected that local availability and the cost will improve in future.

3.2 *Building Systems*

The inclusion of a mechanical ventilation system with heat recovery is not mainstream practice in Ireland. This system is essential in air tight buildings, to ensure adequate ventilation and heat recovery. The current Irish Building Regulations, Technical Guidance Document F (TGD Part F) relating to ventilation, requires to naturally ventilate dwellings, with mechanical extract from kitchens and bathrooms. Nevertheless, high efficiency whole house mechanical ventilation systems have become more available in Ireland recently. Barriers to their integration include sizing and sourcing the appropriate ventilation systems and appropriate location and insulation of ducts as well as pre commissioning testing.

In Low energy dwellings space heating demand is reduced to a point where the traditional heating system becomes obsolete. There are different methods in which to produce the remaining heat demand, for example by pre-heating ventilation air, or installing low temperature radiators. To this extent, different technologies might be used. Some examples include: heat pump with geothermal heat and solar thermal collectors supplying a small central low temperature floor heating system; small biomass boiler and solar thermal collectors supplying low temperature heating system; district heating (water) and solar thermal collectors supplying heat to ventilation air and one radiator in the bathroom.

Common practice in Ireland is to use oil fired, or where available, natural gas boiler with water as heating fluid for space heating. Increasingly, gas condensing boilers are used with thermostat control and radiator panels. Barriers that have been identified with respect to minimal space heating solutions include: solar thermal collectors for space heating and or water heating applications are an extra cost without funding support. Heat pumps and low temperature under floor heating are becoming more widespread, although they as well are considered expensive without funding. Wood pellet burners have become more widespread recently, with systems manufactured in Ireland and funding available to install in dwellings.

Generally the DHW heating system in low energy dwellings is combined with the source for the space heating system. Usual systems include: heat pump on geothermal heat and solar thermal collectors and/or gas heater; small biomass boiler and solar thermal collectors. So far in Ireland, a low energy dwelling typical system includes a wood pellet boiler with solar collectors, combined with space heating. Although a wide range of solar thermal domestic hot water systems are available in Ireland, barrier to widespread application is the availability of training and certification schemes for designers and installers.

4 CONCLUSIONS

Most frequently encountered technical barriers in Ireland to building low energy dwellings include:

- Failure of housing developers to adopt new construction techniques
- Limited knowledge amongst planners, designers, builders and installers
- Unavailability of components, i.e. triple glazed windows and high efficient doors locally. As demand increases it is expected that local availability will improve.
- Limited on site contractor skills and experience
- Limited knowledge of issues such as thermal bridges and air-tightness at design detailing stage and failure to achieve on site
- Cavity wall building technology has to be adapted to the low energy concept or different building systems adopted
- Lack of components such as wall ties and lintels to build traditional wall types to higher energy performance levels.
- Consumer habits - traditionally an expectation of open fireplaces.

Based on the issues raised, approaches to overcome barriers is the provision of practical information and solutions to building professionals, providing practical and training to installers and contractors and dissemination of the low energy concept to the market, potential buyers building users.

5 REFERENCES

Brophy, V., Clinch, J.P., Convery, F.J., Healy, J.D., King, C. and Lewis, J.O. *Homes for the 21st Century - The Costs & Benefits of Comfortable Housing for Ireland*. Report prepared for Energy Action Ltd. Dublin. 1999

Department of the Environment, Heritage and Local Government, *Technical Guidance Document Part L: Conservation of fuel and energy*. 2002.

Department of the Environment, Heritage and Local Government, 2006. *Housing Statistics, Annual and Quarterly Bulletins. Available* :http://www.environ.ie/DOEI/DOEIPub.nsf/wvNavView/RegularPublications?OpenDocument&Lang=en#I2 (Accessed April 2007).

Environmental Protection Agency. *Ireland's Emissions of Greenhouse Gases – Revised and Updated Figures*. 2006.

Sustainable Energy Ireland. *Energy Consumption and CO_2 Emissions in the Residential Sector: 1990-2004.* SEI Energy Policy Statistical Support Unit. 2005.

Kondratenko, I. Brophy, V. Hernandez, P, Burke, K. *Potential for Energy and CO2 Emission Savings through the Application of the Passive House Standard in Ireland*, International Conference on Passive House 2006, Hannover, Germany. May 2006.

Hernandez, P., Lewis, O.J. *Current practice in Domestic Solar Water Heating Installations in Ireland.* Energy Research Group, University College Dublin. World Renewable Energy Congress (WREC 2005) Editors M. S. Imbabi and C. P. Mitchell (C) 2005 Elsevier Ltd. P 57-62.

Shanks, K., Wardell, G., MacPhaidin, A. *Energy Impact of airtightness in Irish housing.* Paper published in the conference proceedings Renewable Energy in Maritime Island Climates, Dublin, Ire land April 2006. pp 235-240.

Service life prediction for buildings' design to plan a sustainable building maintenance

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ABSTRACT: To plan maintenance in a sustainable building process development it's necessary to have a good information about building components and materials durability. The construction works have to be maintained during their whole service life, an activity for which the maintenance manager organisation is responsible: service life's knowledge becomes a very important input data to guide designers, manufacturers and real estate owners in contributing for sustainable building processes.

The report deals specifically with the definition of original tools and methods to evaluate service life, describing the activities undertaken by the Research Group on Durability of Building Components, at Politecnico di Milano, on the development of an Italian durability research network. The application of these methods allows a real implementation of the Performance Based Approach in the construction industry, specifically in design and management stages.In particular, Politecnico di Milano has developed a method based on the correlation between users' requirements and measured decays of performance characteristics of building components: the Limit Performance Method.

Service life management systems are, eventually, analysed from the point of view of the information due to allow designers to manage service life prediction and maintenance planning: ICT tools need Reference Service Life Data Bases, as Politecnico di Milano is structuring.

1 INTRODUCTION

The sustainability of building process requires the control and planning of material and economic resources necessary for its life cycle. Design choices should be oriented towards building's components and products characterised by an economically reasonable working life, i.e. which requires economically and materially sustainable maintenance activities, considering the predicted service life. Then the Building Science is needed to place adequate information at designers' disposal to work out such choices.

With this aim different researches and standards have been developed at national and international level on durability evaluation. At international level ISO TC 59 SC14 Service Life planning and CIB W80 RILEM Service life prediction methodologies are developing durability evaluation methods to support service life planning.

The Building Durability Group of Politecnico di Milano has been developing a research to set up methods for building components durability evaluation, applying them to external wall's components.

2 PAPER

In 2003, with the co-financing of Ministry of Instruction, University and Research, in Italy a pluriannual research on "Methodologies of planning and valuating durability of buildings' components for sustainable production processes" started: the proposed research program develops methodologies applicable to designing, experiencing the valuation method on one range of building components, belonging to the classes of external walls, external casings, continuous and discontinuous coverings.

In this program, six research units of as many Italian university centres are involved: Politecnico di Milano, Politecnico di Torino, University of Naples, University of Palermo, University of Brescia and University of Catania.

Thanks to this programme, it has been created a meaningful methodological-experimental reference for the developing of a national net of systematic experimentation on building components' durability for sustainable designing managed in technological laboratories (tests of accelerated aging in standard conditions) and monitoring of the out-exposed specimens for "re-scaling" results coming from accelerated tests.

The chief objective is to develop interoperable modular ICT tools (SW/ Web Services) to plan and manage works, responding to the demands and requirements of Designers, Maintenance Planners, Real Estate and Facility Managers and contributing to drive designing choices in civil application from a sustainable point of view.

The tools will focus on service life and maintenance issues, relate to sustainability aspects, and will take into account the knowledge acquired on Service Life Prediction Methods to plan maintenance and inspection. Such tools will allow economic planning considering Life Cycle Costs and sustainability evaluation considering Life Cycle Assessment (LCA).

Moreover, the purpose is to provide a graduate acquaintance of durability, contributing to the international research of CIB and also developing ISO standards in this field through the Italian National Agency of Standardization (UNI).

A particularly meaningful and innovative aim of this research is also to determine the conventional performance limits of each building's component in order to recognize the reaching of the end of service life, providing, moreover, an ingegneristic method as suggested from ISO standards for doing it. Thanks to the cooperation among the six Italian research units, service life prediction tools will take the input data from a set of the national regionalized information sources, a Reference Service Life Database, contemplating also a performance evaluation for feedback of service life data from practice, with an agreed European international structure (in conformity with ISO 15686).

At the moment, the developed research is focused on the appraisal of building components' durability pursued on a deepening of evaluation methods indicated by ISO 15686, which has carried to the emanation in the 2006 of UNI 11156 "Valutazione della durabilità dei componenti edilizi". These methods are:

– the method for valuating building component's reliability, which can be applied starting from a careful examination of component's design through a functional and technical analysis of the design itself. These analysis evaluate the four components of reliability (functional, executive, inherent and critical), following precise procedural indications. The average of the four reliabilities' values calculated is assumed as propensity to reliability of the building component's spontaneous duration.
– the "Failure Modes and Effects Analysis (FMEA): through a systematic analysis of the building organism decomposed in its fundamental components, this method concurs to give precious information in perspective of a maintenance programming. Its application produces an exhaustive list of all the scenes of degradations that could happen in the various steps of building process.
– the method of evaluation of building components' durability: it provides values of service life in conventional conditions of reference (Reference Service Life), input data to determine the Estimated Service Life trough a correction made by the designer of this value which takes into account the real context of exposition, of production, of use and of maintenance; this method consists, from one side, of aging accelerated testing on building components in laboratory and, from the other side, of studying the external natural aging. The results' compari-

son provides to obtain the temporal re-scaling factor between the two kind of aging and, therefore, to estimate Reference Service Life.

Among these methods, the factorial method, in particular, gives an easy contextualization of Reference Service Life values of building components outside the system and the specific context of design. This method is considered one of the main international references within ISO for the valuation of building component's service life in the specific conditions of use. In particular, the research suggests for this method some criteria in order to make more objective and scientifically validated the values attributed to each single factor.

Moreover, there is the performance limits method (PLM), which belongs to the family of ingegneristic methods and is born from the consideration that the service life prevision must necessarily be based on a performance concept; the idea is to directly correlate building component's service life with environmental performances (thermal hygrometrical comfort) of the space that the components itself delimits, in order to accomplish a durabilistic analysis on the capacity to maintain during its service life the performances for which such components has been thought, planned and realized.

This last method, the performance limits one, consists of the four following fundamental moments:

– definition of performance targets;
– individuation of requirements and specification of performances that the component must supply;
– translation of performance specifications into technical specifics of functional characteristics and individuation of performance thresholds for service life;
– valuation of service life.

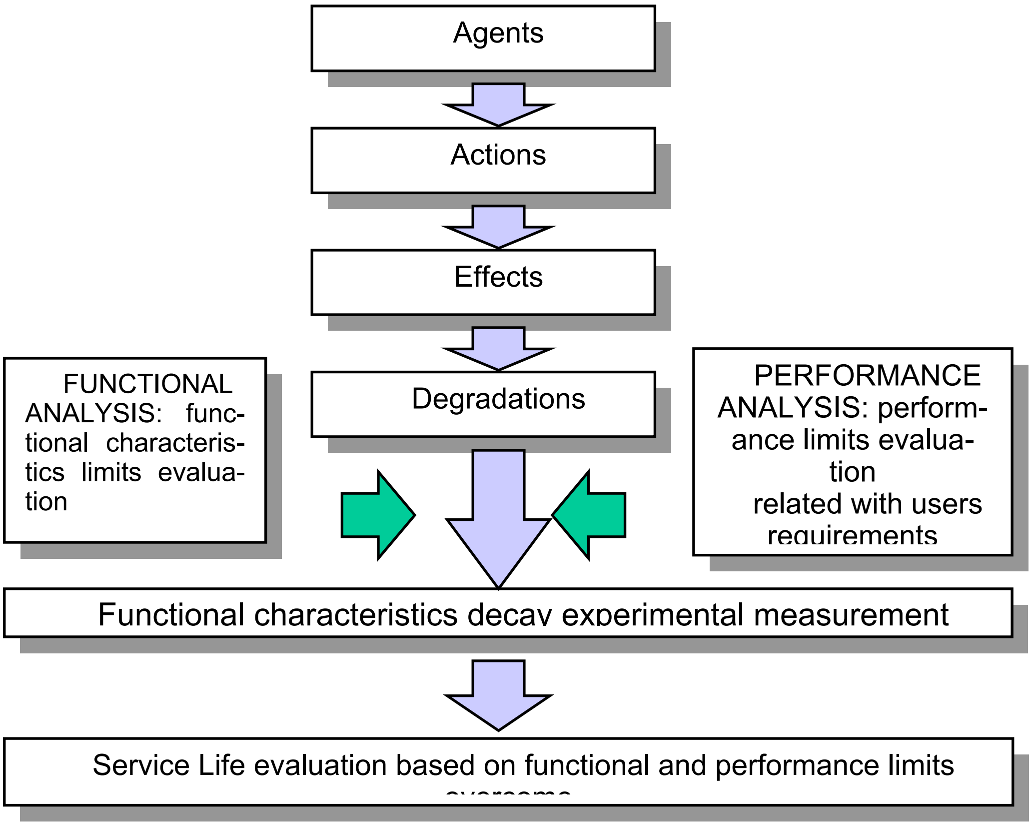

Figure 1 - Analyses scheme for building components' durability evaluation

The international standards developed by ISO TC 59 SC 14 Service Life Planning (ISO 15686-1 and ISO 15686-2) introduces a general evaluation methodology divided in two steps:

- the experimental evaluation of Reference Service Life (RSL);
- the prediction of Estimated Service Life (ESL)for the design stage.

With this aim, the method to predict reference service lives of building components, (i.e. the period of time, after installation, during which a building component meets or exceeds performance requirements in normal conditions of use and maintenance), refinement of a CIB W80 work, has been divided into the following six main point:

- definition of user requirements, and of agents influencing building behaviour (aging agents, location, etc…), the characterization of building material, etc;
- preparation: identification of degradation agents, mechanisms and effects, choice of performance characteristics and evaluation techniques, feedback from other studies;
- pre-testing session in order to check mechanisms and loads and to verify the choice of characteristics and technique;
- exposure and evaluation phase: short term exposure and long term exposure degradations are compared;
- analysis and data elaboration: if degradations are similar the performance during time are evaluated and the Reference Service Life of the component is calculated.

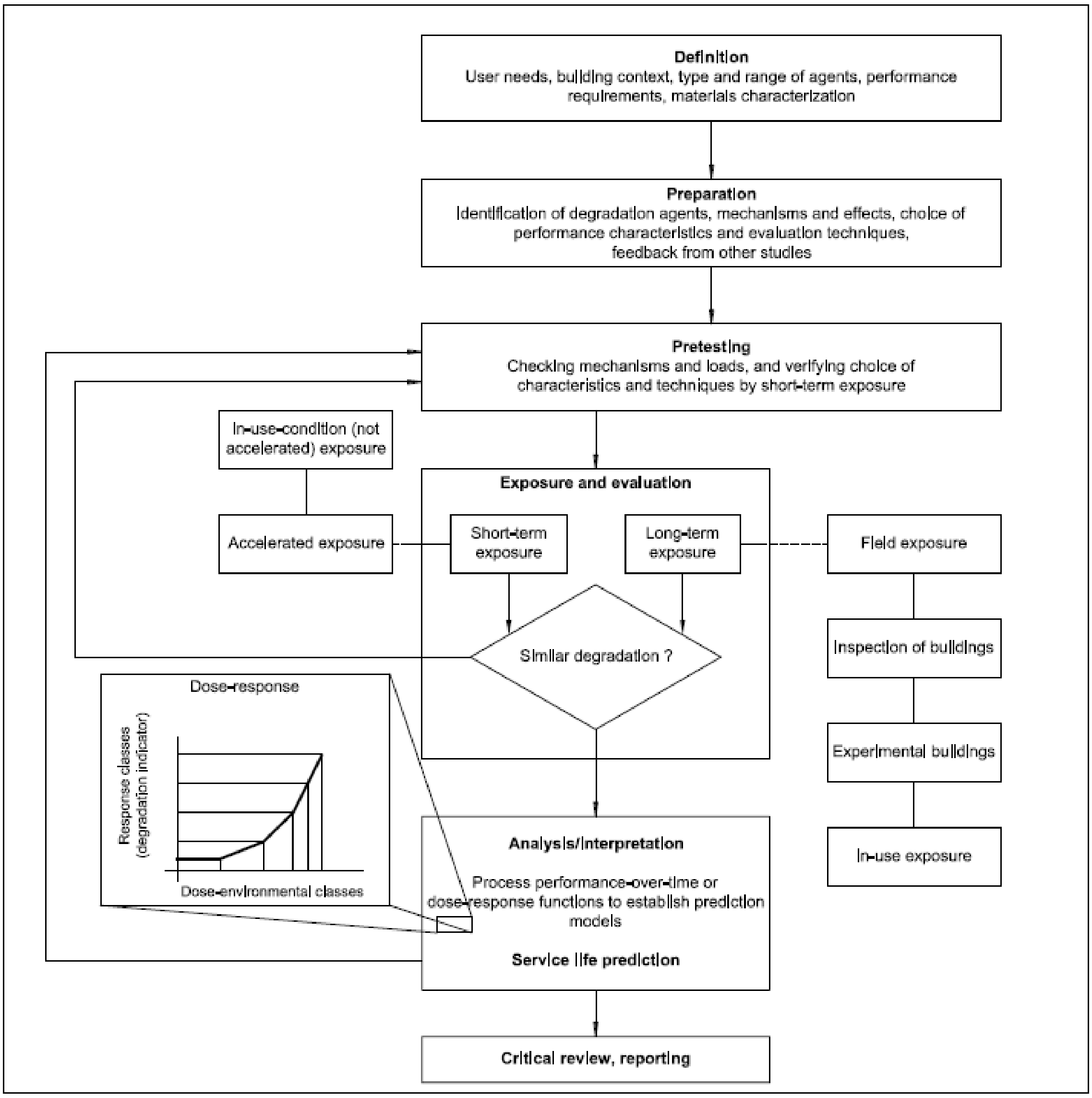

Figure 2 - Methodology the experimental evaluation of Reference Service Life (RSL)

Following this procedure, Politecnico of Milano's Durability Building Component Group has been evaluating Reference Service Life of different components belonging to not bearing external walls class trough the comparison between results obtained by accelerated ageing proofs made in laboratory with those obtained by natural ageing trough external exposition for the technical tiled solution with thermal insulator inside (in order to evaluate the so called "time re-scaling" factor, which brings to the definition of Reference Service Life, in particular, of the external protecting covering layer).

It has been studied both the technical solution composed of a double tile masonry with an interposed layer of insulation, with both surfaces sprayed with plaster and the external one with a layer of protecting paint (one the most used solution still today, especially for residential buildings) and another diffused technical solution belonging to ETICS (External Thermal Insulation Composite Systems).

The results of reference service life evaluations through this procedure can be elaborated to obtain Estimated Service Life in design conditions using one of the following three kind of methods, which differ as for complexity degree, and as for information quantity needed to apply it:

- Factor method: s a simplified method which allows to calculate Estimated Service Life, by correcting Reference Service Life with multiplicative factors (usually between 0.8 e 1.2) which take into account the specific conditions where the component is used. The method is appreciated because of its simplicity which allows to apply it economically to little dimensions housing; this simplicity is however related with its limits of reliability due to the subjectivity to forecast values for each factor;

AGENTS	RELEVANT FACTORS		
Agent related to the inherent quality characteristics	A	Quality of components	Manufacture, storage, transport, materials, protective coatings (factory-applied)
	B	Design level	Incorporation, sheltering by rest of structure
	C	Work execution level	Site management, level of workmanship, climatic conditions during execution of the work
Environment	D	Indoor environment	Aggressiveness of environment, ventilation, condensation
	E	Outdoor environment	Elevation of the building, microenvironment conditions, traffic emissions, weathering factors
Operation conditions	F	In-use conditions	Mechanical impact, category of users, wear and tear
	G	Maintenance level	Quality and frequency of maintenance, accessibility for maintenance

Figure 3 - *Factors used for the factor method*

- Statistical methods: in these methods degradation is generally regarded as a stochastic process, for each property during each time period, a probability of deterioration is defined (models like the Markov chain model are usually used). These methods require fairly sophisticated inputs in the form of probabilities, which are not easily estimated, and require quite some effort to be put in. Most of them are focused on one single material (almost always on reinforced concrete) and on one single aging agent (quite often chloride attack).
- Engineering methods: must have the same degree of complexity of other common design task (i.e. structural analysis, thermal analysis, etc.) and they may have probabilistic inputs but these inputs must be linked by simple, determinate equations. No examples of engineering methods could be found in literature.

In parallel with the experimental activity conducted, Durability Building Components Group of Politecnico di Milano has contributed to the developing of methods for the appraisal of building components' durability, useful for the prevision of Service Life and of reliability propensity during the design step. A particular attention has been focused on the Factorial Method, on the

Performance Limit Method and on Failure Modes, Effects and Criticality Analysis (FMECA).

About the Factorial Method, the research group has defined some criteria in order to make as more objective and scientifically validated as possible values given to each single factor. In fact, ISO 15686 has provided a very simple method for evaluating service life, the factorial method: thanks to seven deterministic factors, this method tries to model aleatory phenomena, such as climatic agents. That's the reason why the scientific community has showed the necessity to improve the method, through two ways to proceed.

The first way is based on a probabilistic approach and uses the same equation proposed by ISO standard, but treating factors as aleatory variables. The DBCG's proposal is based on the use of triangular distributions of ISO factors, adopting Montecarlo method for solving the equation. Aleatory variables' use describes better the complexity of decay and provides both the Service Life and an esteem of data's reliability: it is possible to obtain a evaluation of duration with precise probabilistic guarantees.

Despite this, the factorial method still remains too subjective, because of the subjectivity in choosing factors.

The second way of proceeding suggested by Politecnico di Milano's research group in order to limit choosing factors subjectivity is to adopt guiding grids which drive the designer in assigning values to each factor.

These grids, obviously, can't avoid the subjectivity in calculating Service Life, but they move it in the moment of grid creation: that' why grids should be built by building sector experienced people, such as manufacturers themselves.

Using the factorial method, Politecnico di Milano is also structuring a service life data collection of opaque vertical and horizontal enclosures taking into consideration different climatic contests; it is a collection of Reference Service Life values for different technical solutions among opaque vertical and horizontal enclosures, such as:

- traditional walls (double boarding of hollow and semi-hollow bricks with heat insulation interposed);
- externally thermal insulated walls;
- ceilings;
- enclosures typical of the Mediterranean contest.

Initially, the problem to solve is to defined the range of the study established, including identification or specification of essential data, depending on the aim and ambition of the SLP and on the level of existing knowledge of the component.

Two extreme ranges are as follows:

a) specific study: this is intended to focus on a rather specific application of the component tested in terms of service environment and usage with a specified set of performance requirements

b) general study: this is intended to cover a broad application of the component tested in terms of service environment and usage with an unspecified or a loosely specified set of performance requirements. The aim is to establish performance-over-time functions for the performance characteristics chosen in the whole range of applications.

Beside the methods to evaluate Service Life, Politecnico di Milano has developed a method for the evaluation of reliability propensity for the designed building components, then receipted by the Italian UNI standard on "The evaluation of building components' durability", to allow a first estimate of the probability for the component to maintain during time its performance levels, guaranteeing its designed functions.

The building component's reliability propensity is evaluated through the following four aspects.

- functional reliability: balance degree in the distribution of the analytical functions in the functional elements of the component estimating through the observation of the functional model of the component. It's an index of the stress to which the component will be subjected in its practice phase.

- executive reliability: degree of foreseeable conformity of the component execution at the intentions of the project. It's an index of the foreseeable precision in the installation of the component.

- inherent reliability: degree of evenness of dimensional changes between the functional elements of the component throughout its performance in comparison with the stress context. It's an index of functional integrity of the component in its practice phase.

- critical reliability: degree of chemical-physical compatibility which characterizes the different materials making up the functional elements of a component. It's an index of structural integrity of the component.

3 CONCLUSIONS

It is not possible to talk about sustainability in building process without considering the importance of building components' durability. That's why the choice of technological low energy components can be wrong if their duration is too short.
The evaluation of service life, according to international ISO and national UNI standards, can be made following some different methods porposed. Politecnico di Milano is developing these methods, looking in particular an implementation of the Performance Based Approach in the construction industry, specifically in the design and management stages.

Analysing service life management systems form the point of view of the information due to allow designers to manage service life prediction and maintenance planning, Politecnico di Milano is structuring a Reference Service Life Data Bases thanks also to the Italian research durability network; that's the input needed by ICT tools to manage service life prediction in order to plan a sustainable building maintenance.

REFERENCES

Hallberg D., *Development and adaptation of a life cycle management system for construction works.*

Re Cecconi F., 2004, *Engineering method for service life planning: the evolved factor method*, in papers of the conference CIB World Buiding Congress, Toronto.

Daniotti, B., 2005, La durabilità in edilizia, CUSL, Milano.

Daniotti, B., 2006, La valutazione della durabilità di pareti perimetrali verticali non portanti, Ed. Editecnica, Palermo.

ISO 15686-1:2000, *Building and constructed assets – Service life planning: General principles*.

ISO 15686-2:2001, *Building and constructed assets – Service life planning: Service life prediction procedures*.

UNI 11156:06, La valutazione della durabilità dei componenti edilizi.

Durability design of metal structures based on lifetime safety factor method

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ABSTRACT: Durability design of new and existing structures is a key issue for the sustainable development of built-up environment. While the design procedure for reinforced concrete constructions was deeply investigated, the durability evaluation of metal structures has still to be fully analyzed and codified. The aim of this paper is to provide a first proposal for a general approach to the durability design of metal structures based on lifetime safety factor method. All the phases relevant to the design procedure have been discussed and defined in detail, according to a performance based approach. In particular, among the environmental deteriorating mechanisms which affect the durability of metal constructions, the atmospheric corrosion was considered. On the basis of the selected probabilistic corrosion models, which take into account different metal materials, corrosiveness of environment and effectiveness of coatings, the procedure for evaluating the design life corresponding to different environmental loads and limit states has been defined.

1 INTRODUCTION

Sustainable Development (*SD*) was defined for the first time in the last 80s in the Brundtland Report (WCED 1987) as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". In the beginnings the strategic objectives just focused on environmental protection, while nowadays the field of interest has greatly enlarged, including also economic and social concerns.

Among different human activities, which interact with the three *SD* dimensions, the construction sector plays an important role in delivering sustainable development requirements. Review of literature shows that the definition of a sustainable construction implies several statements, such as the efficient use of raw materials, the minimum use of energy and emissions during service life, the life duration and robustness, and a prolonged service life as target (CIB 1999).

Metal constructions can easily satisfy the above mentioned requirements thanks to different features. They are recyclable and have high structural efficiency, design and manufacturing flexibility and speed of building. Such advantages provide lower raw material consumption, facilitate changing requirements avoiding obsolescence, and reduce the construction activities impact on the local environment by reducing emissions and noises.

Despite all the previous advantages, metal structures present some drawbacks, which are mainly related to durability, whose evaluation is necessary for a suitable maintenance and rehabilitation planning during life span.

Among several factors that affect the life duration of metal structures, the atmospheric corrosion is recognized to be one of the major risk which decreases the performance of constructions, resulting in huge economic and societal losses.

In terms of structural effects, the atmospheric corrosion causes the thickness loss of the cross section that leads to a smaller resistant area. The loading capacity of the element itself is reduced and the safety margin rapidly decreases.

Besides the effects on coatings, which could modify the exterior appearance of constructions reducing their aesthetic and economic value, corrosion represents an additional critical load which is able to lead the structures to collapse, specially when it is associated with high stress rates and cyclic loads, such as in the cases of stress and fatigue corrosion (Figure 1).

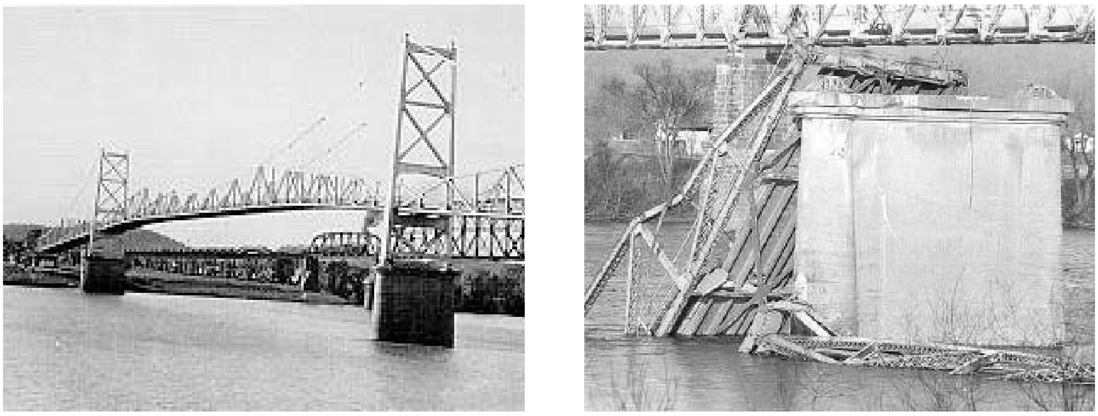


Figure 1. Collapse of the *Silver Bridge* on the Ohio River due to stress and fatigue corrosion (USA, 1967).

With regard to life duration, even if international standards and codes provide general recommendations for preventing early ageing of constructions, the durability design of metal structures has still to be fully defined and codified. In particular, a procedure for the evaluation of original and residual service life should be developed for each material under assigned environmental loads on the basis of available degradation models.

This paper represents a first attempt to propose and develop a durability design procedure for both new and existing metal structures with the aim of evaluating the residual service life of constructions with respect to corrosion degradation.

2 DURABILITY CRITERIA IN STANDARDS AND CODES

The main European standards and codes on constructions give only few qualitative and common provisions for durability of metal structures, that are mainly concerned with coating corrosion or with general recommendations on structural material redundancy. No specific design procedure is provided for the evaluation of design life time of constructions under the identified environmental loads.

A specific definition of durability with respect to the corrosion of metal structures is provided in ISO 8044 (1999), stating that durability is the capability of corrosion system, that is the metal itself or the coating, to fulfill the serviceability requirements for a specific period of time, when adequate maintenance actions are performed.

In EN 1993-1-1 (2004) only few common principles are stated for durability of metal structures and in particular for preventing steel buildings from possible causes of corrosion damage. The code refers to EN 1990 (2001) for durability in general and gives some recommendations such as the opportunity of providing corrosion protection measures by means of surface protection systems, improving the use of weathering or stainless steel and resorting to structural redundancy. However, in such a case no references are made to models able to estimate the corrosion depth as a function of time and of the different factors influencing the degradation rate.

Even if durability is analyzed in general terms, it should be noted also that in some codes for metal structures (DM 2005), an important innovation is being introduced concerning corrosion, which is expressly included among the different loads acting on constructions. In these standards corrosion is classified as a type of entropic load, which comprises deteriorating actions, caused by natural degradation mechanism of materials, and environmental loads, which affects the structural integrity.

Some specific references to durability are reported in the international standards with respect to life duration of the different coating protective systems.

EN ISO 12944-1 (1998) sets three durability classes with regard to protective paint system. In particular, durability means how long the protective coating is effective before a maintenance provisions have to be performed. The standard defines three durability classes: Low (from 2 years up to 5), Medium (from 5 years up to 15) and High (more than 15 years).

In EN ISO 14713 (1999), the life duration of zinc and aluminium coatings is related both to thickness loss and corrosiveness of environment. In particular, specific recommendations are given for each corrosivity class with respect to different coating typologies. However, it should be noted that in this case the design life of coating thickness is evaluated on the basis of linear extrapolation of corrosion rates per year.

Many other references (EN ISO 9226 1992) can be found in international standards, but a design procedure has still to be codified for predicting and preventing the potential damage that a specific environment could lead to both coatings and structural materials, during the entire service life. Taking into account the lack of codified durability design procedures, the application of the life time safety factor method to metal structures is discussed in the following.

3 DURABILITY ANALYSIS BASED ON LIFETIME SAFETY FACTOR METHOD

The lifetime safety factor method in durability design was first time presented in the RILEM Report on concrete structures (Sarja & Vesikari 1996) and then developed within the framework of the EU Project LIFECON (Sarja 2004).

The method is used for the calculation of design life of constructions and it is based on probabilistic degradation models, which consider the decrease of structural resistance caused by different classes of environmental loads. It is so called because of the safety factor applied to the average or the characteristic value of design life. The latter is calculated by degradation models, taking into account both the statistical values of resistance and loads and it is calibrated on the maximum allowable failure probability related to the considered limit states.

Such design approach belongs to semi-probabilistic methods. In this case, both the resistance R and the action effects E are considered as independent random variables. The failure probability P_f is conventionally defined by the reliability index β, which is related to P_f by the equation $P_f = \Phi(\beta)$, where Φ is the cumulative distribution function of the standardized normal distribution. According to semi-probabilistic methods, the design values of the basic variables X_d and F_d influencing both R and E are introduced with their characteristic values divided or multiplied by partial factors. Such partial safety factors are calibrated in order to satisfy the equation $P_f \leq P^*_f$ when $E_d \leq R_d$, where P^*_f is the maximum allowable failure probability relevant to the considered limit state.

The durability design based on lifetime safety factor method is analogous with the static limit state design. In particular, it is related to control the failure probability by considering the effects on R of the environmental loads acting during the entire life time cycle, while static limit state design is devoted to control the structural reliability of constructions under external mechanical loading. In durability limit state design the resistance R is considered as a time dependant variable, contrary to static limit state design, where the effects of time are usually neglected for R (Figure 2).

In particular, a deterioration function D can be formulated on the basis of the time dependant resistance R according to formula:

$$D(t)= R(0)-R(t) \tag{1}$$

where: $D(t)$ is the deterioration at time t; $R(0)$, $R(t)$ are respectively the resistance at t=0 and at the generic time t of the life cycle.

Because of the different sources of uncertainties that are involved in the definition of the variation of capacity with time, the values in the previous equation are usually taken as mean or characteristic values. The load S is usually adopted to be constant with time, and its design value is also taken as a mean or characteristic value, multiplied by the relevant safety factors.

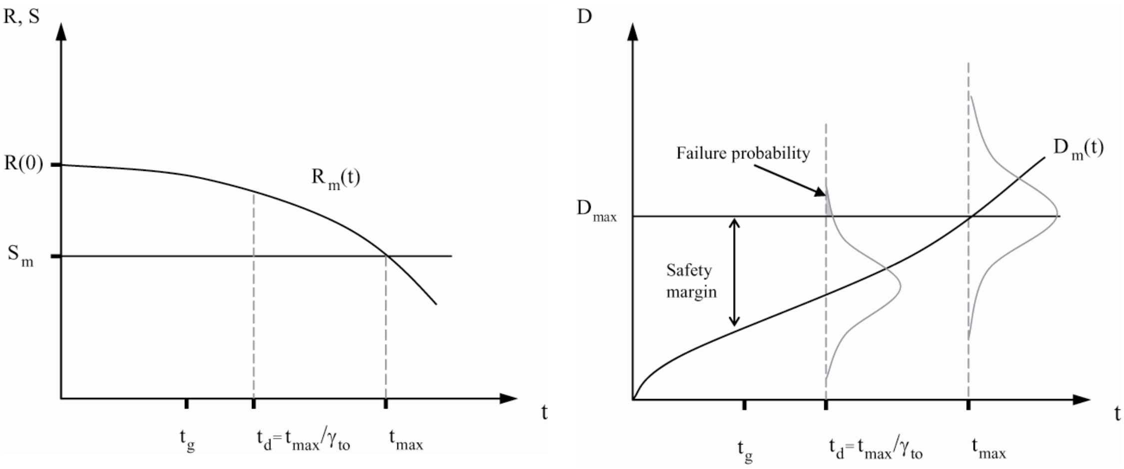


Figure 2. Representation of the life time safety factor design approach by *R, S, t* and *D, t* variables.

The failure event corresponds to time t_{max} when the capacity R is equal to load S. The difference $R(t)-S$ represents the reduction with time of the safety margin:

$$R(t_{max})=S \quad (2)$$

On the basis of previous considerations, a durability design procedure organized into different steps can be formulated, as specified in the following.

First, the target service life t_g has to be defined for the considered constructions. The target service life must be specified as a basis for assessing statistically variable actions and to evaluate the reliability with respect to durability. Target service life is assumed to be the time period for which a structure or part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary (EN 1990 2001). The numerical reference values are selected according to common standards, regulations and codes. The standard EN 1990, with respect to target service life, defines different indicative values on the basis of the construction characteristics, typology and use (e.g. 50 years for building structures and other common structures, 100 years for monumental building structures, bridges, and others). The reference value of the target service life has to be selected according to mechanical design procedure.

Once the reference period has been stated, it is possible to identify the environmental loads S that will likely act onto structure. Each environmental load is analysed and quantified, where relevant, in a statistic way. The analysis of the environmental condition has to be performed in order to define the project background. With regard to atmospheric corrosion of metal structures the identification of both the climatic conditions (such as temperature, rain, condensation of moisture, freezing, solar radiation and air pollution), and the geological conditions (such as the location of ground water, possible contact with sea water, contamination of the soil by aggressive agents like sulphates and chlorides) has to be provided.

On the basis of the identification of environmental loads, the degradation factors and mechanisms should be evaluated.

Once deterioration mechanisms that could act onto structures during the life cycle have been identified, corresponding damage curves should be considered as a function of time in the form:

$$D_m(t) = \alpha \cdot t^n \quad (3)$$

where: $D_m(t)$ is the mean value of degradation; α is a constant coefficient; t time; n degradation mode coefficient.

Substituting t_{max} in eq. (3), we have:

$$D_m(t_{max})=D_{max} \quad (4)$$

where $D_{max}=R(0)-R(t_{max})=R(0)-S$ represents the maximum allowable value of degradation (e.g. the maximum allowable mass loss and/or corrosion depth in the cross section of a beam).

Durability requirements are fulfilled if the failure event (4) occurs after the design service life had expired, with a proper safety margin. That could be expressed according to formula:

$$t_d = t_{max}/\gamma_{t0} >= t_g \quad (5)$$

where: t_d is the design service life; t_{max} is the calculated mean value of the service life corresponding to $D(t_{max})=D_{max}$; γ_{t0} is the central lifetime safety factor; t_g is the target service life.

Assuming that degradation is normally distributed and the standard deviation of D is proportional to the mean degradation, the coefficient of variation V_D being constant, it can be shown that the central lifetime safety factor of the design life depends only on safety reliability index, the coefficient of variation of D and the exponent n, according to the formula:

$$\gamma_{t0} = (\beta \cdot V_D + 1)^{1/n} \quad (6)$$

On the basis of such assumptions, the safety reliability index β depends on both the maximum allowable failure probability for the selected limit state and the degradation function. In particular, it is a function of the mean values and standard deviations of R and S, as follows:

$$\beta = (\mu_R - \mu_S)/(\sqrt{\sigma_R^2 + \sigma_S^2}) \quad (7)$$

In the following sections, all the phases of the durability design procedure for metal structures are discussed in detail with respect to degradation due to atmospheric corrosion.

4 ENVIRONMENTAL LOADS: THE ATMOSPHERIC CORROSION

Corrosion is defined as a deterioration of metal materials that results from a reaction with its environment (NACE 2002), causing the degradation of both.

The deterioration is caused by a chemical and/or electrochemical attack of the metal surface. Corrosion processes are influenced by several factors, that could be divided in two broad classes: the endogenous and the exogenous factors. The first ones are related to the metal itself, e.g. the composition of the metal, the chemical and physical homogeneity of the surface. The exogenous factors are associated to the atmospheric composition, such as temperature, relative humidity and concentration of pollutants (Landolfo & Di Lorenzo & Guerrieri 2005).

Depending on the physical and chemical features of the environment, the corrosion phenomena could develop in different forms, and may be uniform or localised.

The atmospheric corrosion is mainly an electrochemical process that occurs when a thin electrolytic layer is formed on the metal surface; the rate at which the corrosion attack proceeds is strictly related to the corrosiveness of the environment. Relative humidity rate, the pollutants (sulphur dioxide, sodium chloride, ammonium sulphate, etc..) the airborne particles, dust, the weather condition, the wind and the temperature average are the main features that characterize the outdoor atmosphere.

5 CLASSIFICATION OF ENVIRONMENTAL LOADS

Within a durability design method, the classification of environmental loads is necessary for evaluating all the factors which affect the degradation rate during life time of constructions.

Several classification systems are provided by standards to assess the corrosiveness of environment. The codes usually provide the corrosivity of the environment on the basis of the mass loss after one-year exposure. It should be noted that these values represent the result of the corrosion attack after one-year and they cannot be extrapolated to estimate the extent of damage in a time t of the service life.

EN ISO 9223 (1992) defines five corrosivity classes C1-C5 on the basis of three key factors: the TOW (time of wetness), the deposition rate of chlorides and sulphures dioxide. EN 12500 (2000) defines the corrosiveness of the environment, according to ISO 9223, by assessing the mass loss of standard samples, after 1 year exposure and it establish five corrosivity categories from C1, very low corrosivity environment, up to C5, very severe corrosiveness atmosphere.

EN 12500 recommends to evaluate the corrosiveness of the environment quantitatively on the basis of the sample exposure but whether impossible, it could be used to assess qualitatively the atmospheric category. The standard points out that the qualitative classification of the environment could mislead designers in selecting protective measures, field test exposure are strongly recommended. According to EN 12550 the designer should run field test on standard carbon steel, zinc, copper and aluminium samples measuring, after 1 year exposure, the mass loss of the samples. The corrosiveness class of the local environment is thus established comparing the measured values with the guiding values reported in the following Table:

Table 1. Mass loss (g/m^2) for one year field test exposure. EN 12550.

MASS LOSS g/m^2				Corrosiveness category	
Carbon Steel	Zinc	Copper	Aluminium		
≤ 10	≤ 0,7	≤ 0,9	Negligible	Very low	C1
10-200	0,7-5	0,9-5	≤ 0,6	Low	C2
200-400	5-15	5-12	0,6-2	Medium	C3
400-650	15-30	12-25	2-5	High	C4
650-1500	30-60	25-50	5-10	Very high	C5

As an alternative to the previous procedure, the corrosiveness of the local environment could be assessed qualitatively on the basis on climatic and/or environmental parameters and/or construction location (EN 12500 2000). The qualitative classification of the atmospheres ranges from Rural to Marine industrial types and it is based on a general description of corrosive agents and degradation rates.

6 DEGRADATION MODELS

Several degradation models can be found in literature which have been defined for metallic materials. These models provide the corrosion depth or the mass loss with time for different corrosive environments. In general, they are formulated according to a probabilistic approach because of the uncertainties which affect degradation rates.

In order to use such models in the durability design of metal structures, it is necessary to relate the classification of the environmental loads to the corresponding corrosion rate. The thickness loss during structural life time can be predicted by means of the considered degradation law and on the basis of assigned environmental conditions.

At this stage of the study, it should be noted that no clear relationship between corrosion models and atmosphere classes are provided by the codes.

In the following, an application of degradation models provided in literature to corrosiveness classes defined in standards is reported. In particular, the corrosion models developed by Klinesmith (2007) are used. Such models were formulated for different materials taking into account the effects of four environmental variables, which are time-of-wetness, sulfur dioxide, salinity, and temperature.

The form of the degradation model is the following:

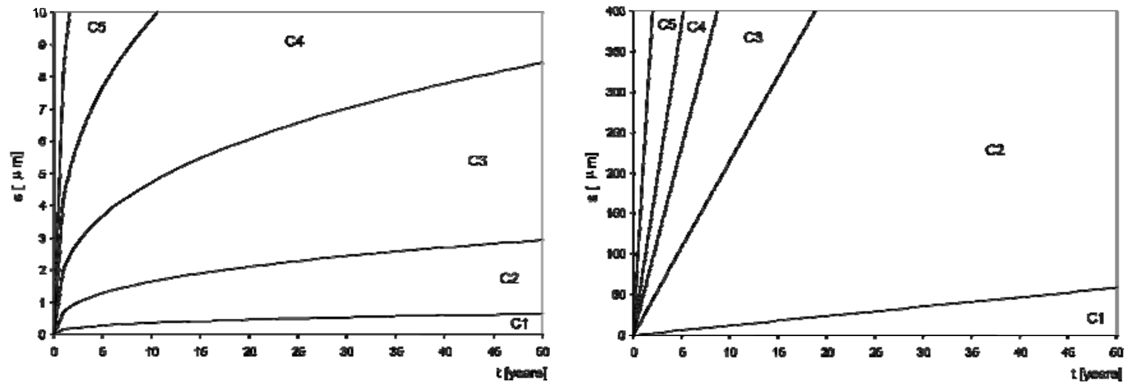
$$y = A \cdot t^B \left(\frac{TOW}{C}\right)^D \cdot \left(1+\frac{SO_2}{E}\right)^F \left(1+\frac{Cl}{G}\right)^H e^{J(T+T_0)} \tag{8}$$

where y=corrosion loss (μm); t=exposure time (years); TOW=time-of-wetness (h/year); SO_2=sulfur dioxide concentration ($\mu g/m^3$); Cl is chloride deposition rate (mg/m^2 /day); T=air temperature (°C); and A, B, C, D, E, F, G, H, J, and T_0 =empirical coefficients.

Table 2. Coefficients of Eq. (8) calibrated with ISO CORRAG data (Dean & Reiser 2002) for carbon steel and zinc materials.

Material	Equation coefficients									
	A	B	C	D	E	F	G	H	J	T_0
Carbon steel	13.4	0.98	3800	0.46	25	0.62	50	0.34	0.016	20
Zinc	0.16	0.36	3800	0.24	25	0.82	50	0.44	0.05	20

The degradation curves for zinc and carbon steel corresponding to the selected model (Table 2) are shown in Figure 3. The environmental variables have been considered with values corresponding to the different corrosiveness classes as defined in EN 12500 (2000).



a) *b)*

Figure 3. Thickness loss as a function of time for zinc (a) and carbon steel (b) for different corrosiveness classes, according to selected degradation models.

7 DURABILITY LIMIT STATES

In order to complete the development of a durability design procedure based on the partial safety factor method, both serviceability and ultimate limit states related to basic requirements need to be defined, such as functionality in use and structural safety. In particular, the definition of the maximum allowable degradation value for each material and limit state and of the relevant reliability index β is necessary for the calculation of design life t_d and of relevant safety factor γ_{t0}.

Durability limit states could be the same of the ones used for mechanical design, but some specific limit states should be defined for durability (Sarja 2004).

Serviceability and ultimate limit states in durability design can be referred to the thickness loss of coating and structural material respectively. In particular, serviceability limit states are related to changes in functionality or aesthetics and they are based on maintainability, economy and environmental impacts. As a consequence, such limit states can be ascribed to the attainment of partial or total loss of coating thickness. On the contrary, ultimate limit states are related to the thickness loss of structural material which compromises the mechanical safety of constructions.

With regard to serviceability limit states (SLS) relevant to zinc coating corrosion, it is suggested to use the definition provided by British Steel Construction Institute research (Popo-Ola & Biddle & Lawson 2000) on durability of galvanized cold formed steel section used in housing. In this case, different limit states have been defined depending on the possibility of a building component to be inspected. In particular, if the use conditions do not allow regular inspections, such as in case of wall frames and wall ties, the limit state is reached when 50% of the weight of zinc has been lost, otherwise for roof trusses and internal floors the limit state is defined as the 80% of the weight of zinc loss.

As far as ultimate limit states (ULS) are concerned, it is proposed to carry out a durability design which is separated from the mechanical one. In particular, the safety of constructions at the end of their life-time should be evaluated by considering the possible thickness loss of structural material which starts after the complete corrosion of coating. Such thickness should be added to the one obtained from mechanical calculation in design phase of new constructions, increasing the structural redundancy, or should be used for evaluating the actual safety factor and the residual service life in existing ones.

In order to evaluate the design service life t_d for different limit states, the central safety factors have to be calculated on the basis of both Eq. (6) and corresponding reliability indexes.

With respect to reliability index β, different values are given by standards and codes for serviceability and ultimate limit states. The reliability indexes to be used in the durability design should be defined close to the mechanical ones but, in order to balance the costs with the benefits, lower reliability level should be tolerated (Sarja 2004). In particular, the suggested values for ultimate and serviceability limit states are equal to 4.3 and 1.5 respectively, in case of reliability class RC2 as defined in EN1990.

By applying the proposed procedure in case of carbon steel and assuming V_d=0.3, the central safety factors calculated by Eq. (6) range from 1.5 to 2.5 for SLS and ULS, respectively. As far as zinc corrosion is concerned, the relevant central safety factor for SLS is equal to 2.8.

8 CONCLUSIONS

This paper focuses on a proposal for durability design of metal structures against corrosion. The different phases of the design procedure have been investigated considering the environmental corrosivity classes defined in current standards and by using degradation models which are available in literature for the calculation of the corresponding thickness loss.
Different limit states corresponding life time safety factors have been proposed, also on the basis of statistical values of considered degradation models.

REFERENCES

CIB 1999. *Agenda21 on Sustainable Construction. CIB Report Publication 237*. Rotterdam: CIB.

CEN 1992. *EN ISO 9223.Corrosion of Metals and Alloys. Corrosivity of Atmospheres. Classification*.

CEN 1992. *EN ISO 9226 Corrosion of metals and alloys. Corrosivity of Atmospheres. Determination of corrosion rate of standard specimens for the evaluation of corrosivity*.

CEN 1998. *EN ISO 12944-1. Corrosion protection of steel structures by protective paint system.*

CEN 1999. *EN ISO 8044. Corrosion of metals and alloys. Basic terms and definitions*.

CEN 1999. *EN ISO 14713. Zinc and aluminum coatings.*

CEN 2000. *EN 12500. Corrosion likelihood in atmospheric environment.*

CEN 2001. *EN 1990. Eurocode. Basis of structural design*

CEN 2004. *EN 1993-1-1. Eurocode3: Design of steel structures. Part 1-1.*

Dean, S. & Reiser, D.B. 2002. *Analysis of long term atmospheric corrosion results from ISO CORRAG Program*. West Conshohocken: ASTM

Italian Government 2005 *Ministerial Decree 14 September 2005.(D.M 2005). Design Rules for buildings*

Klinesmith, D.E. & McCuen R. & Albrecht P. 2007. *Effect of environmental condition on corrosion rate. Journal of Materials in Civil Engineering*.

Landolfo, R.& Di Lorenzo, G.& Guerrieri M.R. 2005. *Modelling of the damage induced by atmospheric corrosion on 19th century iron structures*. Proc. of Italian National Conference on Corrosion and Protection, Senigallia

NACE International. 2002. *Glossary of Corrosion Related Terms*. Houston: NACE International.

Popo-Ola, S.O.& Biddle, A.R. & Lawson R.M.2000. *Durability of light steel framing in residential buildings. SCI Publication P262*.Ascot:The Steel Construction Institute.

Sarja, A .2004. *Lifecon deliverable D2.1. Reliability based methodology for lifetime management of structures*. Finland .

Sarja, A. & Vesikari, E. 1996. *Durability design of concrete structures. RILEM Report of TC 130-CSL.RILEM Report Series 14*.

World Commission on Environment and Development(WCED) 1987.*Our Common Future. Report A/42/427*. United Nation.

The redesign for residual service life of existing structures

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ABSTRACT: A residual survival probability of members and systems of existing structures subjected to extreme service and climate actions is considered. The time-dependent safety margin of particular members (sections, bars, connections) and its modifications as stochastic finite sequences are discussed. The prediction of primary and revised instantaneous and long-term survival probabilities of members is introduced. The effect of deterministic short-term extreme action effects on the values of revised survival probabilities of existing members is based on the concepts of truncated resistance distributions and Bayesian statistical approaches. The revised reliability index of precast concrete floor slabs is considered and demonstrated by the numerical example.

1 INTRODUCTION

For successful ordinary and scheduled maintenances of existing structures, it is necessary to know the revised values of their time-dependent survival probability parameters. The extreme action effects caused by service and climate loads help engineers convince in the absence of rough human design and construction errors. Besides, the fixed values of random extreme action effects assist designers reduce the uncertainties of a performance of particular members (sections, bars, connections) of structures and in this way to revise their survival probability degrees.

Additional information about unfavorable actions and behaviors of overloaded members cannot be used in their capacity assessment. However, information data may be successfully used in the probabilistic reliability prediction of members and systems. It is very possible that the high-reliability degree of structures should be guaranteed if they had already withstood unfavorable extreme loading situations. Thus, extreme action effects of members may be treated as an effective measure in the updated reliability prediction of existing members and their systems when they are confirmed by quality statistical information data (Mori & Ellingwood 1993). These data may help designers refine probability density functions of member resistances if their variances are small (Melchers 1999).

There are some limited attempts to transfer the approaches of deterministic limit state design to the quality analysis of existing structures (Allen 1991). However, this semi-probabilistic reliability analysis format cannot be acknowledged as an universal, convenient and practical method. Therefore, it is expedient to realize the information on service-proven loading situations in engineering practice using probabilistic approaches (Madsen 1987, Ellingwood 1996, Melchers 1999). They allow evaluate objectively all uncertainties of calculation models, design situations and structural performance parameters. However, it is difficult to apply these approaches in engineering practice due to some methodological and mathematical difficulties. Probability-based approaches may be acceptable to structural engineers only under the indispensable and easy perceptible condition that they may be translated into practice using unsophisticated analysis models.

The intention of this paper is to introduce engineers and researchers the concepts of truncated probability distribution and Bayes theorem in the revised reliability prediction of members of existing structures subjected to extreme actions as intermittent rectangular renewal pulse processes.

2 STRUCTURAL SAFETY MARGINS

According Melchers (1999) and JCSS (2000) recommendations, the time-dependent random safety margin of particular members of structures may be defined as their performance process:

$$Z(t) = g\left[\boldsymbol{X}(t), \theta\right] \tag{1}$$

Here the function $g[\bullet]$ is founded by structural mechanics rules, where $\boldsymbol{X}$ and θ are the vectors of basic and additional random variables representing a resistance and action effects of members and their model uncertainties, respectively.

In the contest of the analysis of survival probabilities of members of existing non-deteriorating structures in transient design situations, the process (1) may be presented in more convenient form:

$$Z(t) = \theta_R R - \theta_g S_g - \theta_q S_{q_s}(t) - \theta_q S_{q_e}(t) - \theta_w S_w(t) \tag{2}$$

where R is a member resistance as the stationary process; S_g, S_{q_s}, S_{q_e} and S_w are the action effects caused by permanent g, sustained q_s and extraordinary q_e live loads and lateral (wind) pressure w (Fig.1). The additional variables θ_i may be introduced by their means and standard deviations equal to $\theta_m = 1.0 - 1.05$ and $\sigma\theta = 0.05 - 0.10$ (Hong & Lind 1996, Stewart & Rosowsky 1996, JCSS 2000, Vrowenvelder 2002).

According to the recommendations of international design codes (ISO 2394 1998, EN 1990 2002, JCSS 2000), a Gaussian distribution law is to be used for permanent actions. Lognormal, Weibull and Gamma distributions may be convenient for sustained live loads and an exponential distribution for extraordinary ones (JCSS 2000, Vrowenvelder 2002, Trezos & Thomos 2003). Annual extreme climate actions may be modeled by a Type 1 (Gumbel) distribution of extreme values (Melchers 1999, JCSS 2000).

Not only annual extreme wind w and snow s loads but also the annual extreme sum of stochastic sustained and extraordinary live loads $q(t) = q_s(t) + q_e(t)$ may be modeled as a rectangular renewal pulse process and described by a Type 1 distribution with the coefficient of variation $\delta q = 0.58$ and mean value $q_m = 0.47 q_k$, where q_k is its characteristic value (Rosowsky & Ellingwood 1992).

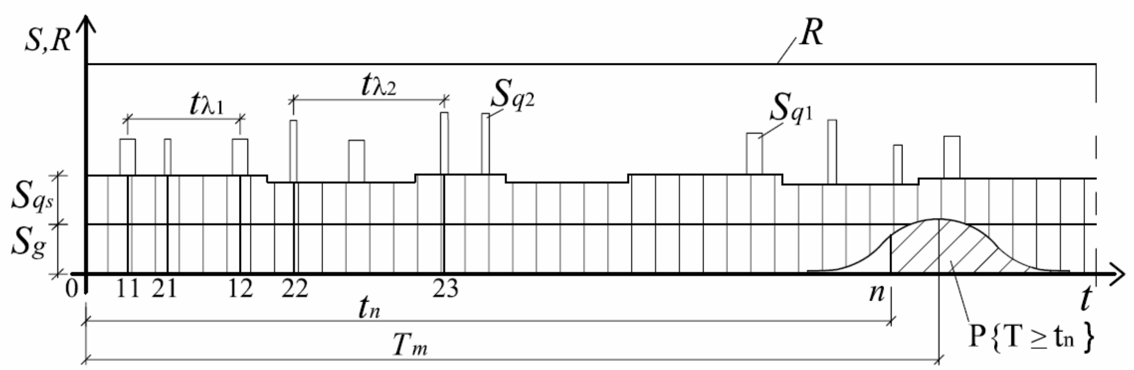

Figure 1. Model for the time-dependent reliability analysis of particular and individual members

For the sake of simplified but fairly exact probabilistic analysis, it is more expedient to present equation (2) in the forms:

$$Z_1(t) = R_{c1} - S_1(t) \tag{3}$$

$$Z_2(t) = R_{c2} - S_2(t) \tag{4}$$

Here

$$R_{c1} = \theta_R R - \theta_g S_g \tag{5}$$

$$S_1(t) = \theta_q S_q(t) + \theta_w S_w(t) \tag{6}$$

$$R_{c2} = \theta_R R - \theta_g S_g - \theta_q S_{q_s} \tag{7}$$

$$S_2(t) = \theta_q S_{q_e}(t) + \theta_w S_w(t) \tag{8}$$

where R_{c1} and R_{c2} are the conventional resistances of members; $S_1(t)$ and $S_2(t)$ are their total annual extreme action effects. The extreme live action effects $\theta_q S_q(t) = \theta_q S_{q_s}(t) + \theta_q S_{q_e}(t)$ and $\theta_q S_{q_e}(t)$ may be modeled respectively by Gumbel and exponential distributions. In the reliability analysis of roof structures, the action effect $\theta_s S_s(t)$ should be used instead of the component $\theta_q S_q(t)$ caused by floor loads.

3 SURVIVAL PROBABILITIES

For structures subjected to intermittent extraordinary gravity or lateral actions, the design cuts of safety margin processes coincide with extreme loading events. Therefore, in design practice the stochastic safety margin of particular members may be treated as the random finite sequence:

$$Z_k = R_c - S_k \quad , k = 1, 2, \dots, n-1, n \tag{9}$$

Here R_c is given by Equations (5) or (7), S_k by (6) or (8); $n = t_n \lambda$ is the recurrence number of recurrent extreme action effects during the design working life of structures t_n, where λ is a renewal rate of these effects.

The instantaneous and long-term survival probabilities of members may be calculated respectively by the Equations:

$$\boldsymbol{P}_k = \boldsymbol{P}\{Z_k > 0\} = \boldsymbol{P}\{R_c > S_k\} = \int_0^\infty f_{R_c}(x) F_{s_k}(x) dx \tag{10}$$

$$\boldsymbol{P}_i = \boldsymbol{P}_k^n \left[1 + \rho_{kl}^a (1/\boldsymbol{P}_k - 1)\right]^{n-1} \tag{11}$$

Here $f_{R_c}(x)$ is the density function of conventional resistances by Equations (5) or (7); $F_{S_k}(x)$ is the cumulative distribution function of action effects by (6) or (8); ρ_{kl} is the coefficient of auto correlation of cuts of safety margin sequences the bond index of which is $a \approx [4{,}5/(1 - 0{,}98\rho_{kl})]^{1/2}$.

When the action effects by Equations (6) and (8) are caused by two extreme loads, three stochastically dependent sequences of safety margins should be considered as follows:

$$Z_{1k} = R_c - S_{1k}\,;\; k = 1,2,\dots,n_1 \tag{12}$$

$$Z_{2k} = R_c - S_{2k}\,;\; k = 1,2,\dots,n_2 \tag{13}$$

$$Z_{3k} = R_c - S_{3k}\,;\; k = 0,\dots,n_3 \tag{14}$$

Here the recurrent number of coincident extreme action effects S_{1k} and S_{2k} may be calculated by the formula:

$$n_3 = t_n (d_1 + d_2) \lambda_1 \lambda_2 \tag{15}$$

where d_1, d_2 and λ_1, λ_2 are the durations and renewal rates of extraordinary loads (Fig.1). In this case, the long-term survival probability of members as rank series stochastic systems with the probabilities $\boldsymbol{P}_1 > \boldsymbol{P}_2 > \boldsymbol{P}_3$ may be introduced as:

$$\boldsymbol{P}_m = \boldsymbol{P}\left\{\bigcap_{i=1}^{3} Z_i > 0\right\} = \boldsymbol{P}_1\boldsymbol{P}_2\boldsymbol{P}_3 \times \left[1+\rho^a_{3/21}\left(\frac{1}{P_2}-1\right)\right] x \left[1+\rho^a_{21}\left(\frac{1}{P_1}-1\right)\right] \quad (16)$$

where P_i is given by Equation (11); $\rho_{3/21} = 0.5(\rho_{31}+\rho_{32})$ is the coefficient of rank correlation of three safety margins.

Analogically, the total survival probabilities of rank series systems consisted of r stochastically dependent members may be expressed as:

$$\boldsymbol{P}_s = \boldsymbol{P}\left\{\bigcap_{j=1}^{r} Z_j > 0\right\} = \prod_{j=1}^{r} \boldsymbol{P}_{mj}\left[1+\rho^a_{r/r-1...1}\left(\frac{1}{\boldsymbol{P}_{r-1}}-1\right)\right] \times \dots$$

$$\times\left[1+\rho^a_{k/k-1...1}\left(\frac{1}{\boldsymbol{P}_{k-1}}-1\right)\right] \times \dots \times \left[1+\rho^a_{21}\left(\frac{1}{\boldsymbol{P}_1}-1\right)\right] \quad (17)$$

where $\rho_{k/k-1...1} = (\rho_{k,k-1}+...+\rho_{k1})/(k-1)$ is the coefficient of cross correlation of rank safety margins of members.

4 ACCOUNT OF TRUNCATED DISTRIBUTION APPROACHES

When an additional information permit to define the deterministic value S_{tr} of extreme action effects $\theta_e S_e$ (either $\theta_q S_{q_e}$ or $\theta_s S_s$ or $\theta_w S_w$) caused by live, snow and wind loads, the prediction of instantaneous survival probabilities of members may be based on the concept of truncated probability distributions (Fig. 2). In this case, the density function of revised conventional resistances of members R_{cr} should be considered as a truncated one. It may be presented as:

$$f_{R_{cr}}(x) = f_{R_c}(x)/\left[1-F_{R_{cr}}(x)\right] \quad (18)$$

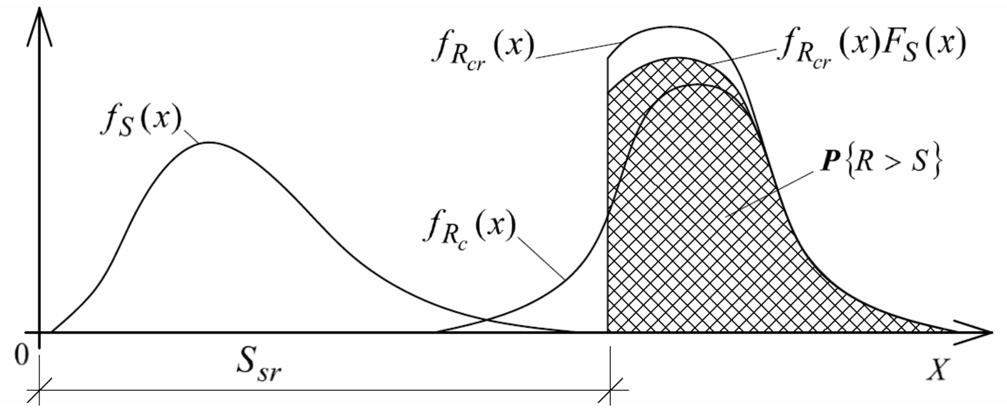

Figure 2. Model for the revised structural safety analysis of members.

The mean and variance of this resistance a probability distribution of unrevised values of which, R_c, is close to a normal distribution may be expressed as:

$$R_{cr,m} = R_{cm} + \lambda\sigma R_c \quad (19)$$

$$\sigma^2 R_{cr} = \sigma^2 R_c\left[1+\lambda\left(\beta_{tr}-\lambda\right)\right] \quad (20)$$

Here the conversional factor of its statistical moments is:

$$\lambda = \varphi(\beta_{tr})/\left[1-\Phi(\beta_{tr})\right] \quad (21)$$

where $\varphi(\beta_{tr})$ and $\Phi(\beta_{tr})$ are the density and cumulative distribution functions of a standard normal distribution of the variable $\beta_{tr} = \left(S_{tr} - R_{cm}\right)/\sigma R_c$.

The revised instantaneous survival probability of members whose successfully have withstood unfavourable extreme action effects may be expressed as:

$$\boldsymbol{P}_{kr} = \boldsymbol{P}\{R_{cr} > S_k\} = \int_0^\infty f_{R_{cr}}(x) F_{S_k}(x) dx \tag{22}$$

The revised long-term survival probabilities of members and systems during their residual service life may be calculated respectively by equations (16) and (17) using the revised values of instantaneous survival probability of members expressed by (22).

5 ACCOUNT OF BAYES THEOREM

According to Tang (1973) and Madsen (1987) recommendations, the updated probability of failure of members can be expressed as follows:

$$\boldsymbol{P}_{kr} = \boldsymbol{P}\{Z_k > 0 \mid H\} = \frac{\boldsymbol{P}\{Z_k > 0 \cap H > 0\}}{\boldsymbol{P}\{H > 0\}} \tag{23}$$

Here the design and inspection instantaneous safety margins of considered members are:

$$Z_k = \theta_R R - \theta_g S_g - \theta_q S_{q_s k} - \theta_e S_{ek} \tag{24}$$

$$H_k = (\theta_R R)_k - \theta_g S_g - \theta_q S_{q_s k} - S_{tr} \tag{25}$$

where S_g, $S_{q_s k}$ and S_{ek} are the action effects caused by random loads where $S_{ek} = S_{qe}$, $S_{ek} = S_{sk}$ and $S_{ek} = S_{wk}$; S_{tr} is the deterministic value of observed extreme action effect; $(\theta_R R)_k$ is the characteristic resistance of a member.

The means and variances of the safety margin functions and the coefficient of their correlation are:

$$Z_{km} = (\theta_R R)_m - (\theta_g S_g)_m - (\theta_q S_{qk})_m - (\theta_e S_{ek})_m \tag{26}$$

$$H_{km} = (\theta_R R)_k - (\theta_g S_g)_m - (\theta_q S_{qk})_m - S_{tr} > 0 \tag{27}$$

$$\sigma^2 Z_k = \sigma^2(\theta_R R) + \sigma^2(\theta_g S_g) + \sigma^2(\theta_q S_{qk}) + \sigma^2(\theta_e S_{ek}) \tag{28}$$

$$\sigma^2 H_k = \sigma^2(\theta_R R) + \sigma^2(\theta_g S_g) + \sigma^2(\theta_q S_{qk}) \tag{29}$$

$$\rho_{ZH} = \rho(Z_k, H_k) = \sigma H_k / \sigma Z_k \tag{30}$$

When an indispensable condition $H_{km} > 0$ is in force, the inspection instantaneous survival probability of considered members is:

$$\boldsymbol{P}_{tr} = \boldsymbol{P}\{H_k > 0\} = \Phi(H_{km} / \sigma H_k) \tag{31}$$

According to the method of transformed conditional probabilities, Equation (23) may be rewritten as follows:

$$\boldsymbol{P}_{rk} = \frac{\boldsymbol{P}\{Z_k > 0\}\boldsymbol{P}\{H_k > 0 \mid Z_k > 0\}}{\boldsymbol{P}\{H_k > 0\}} \approx \boldsymbol{P}\{Z_k > 0\}\left[1 + \rho_{ZH}^{a \cdot \boldsymbol{P}_{tr}} \cdot \left(\frac{1}{\boldsymbol{P}\{Z_k > 0\}} - 1\right)\right] \tag{32}$$

This value of instantaneous survival probability is used in the prediction of long-term survival probabilities of members and systems calculated by Equations (16) and (17).

6 NUMERICAL ILLUSTRATION

Consider the revised survival probability of concrete floor slabs overloaded by the deterministic extreme bending moment $M_{tr} = 140$ kNm caused by the extraordinary service live load. The means and variances of their bending resistance and bending moments caused by permanent, sustained and extraordinary service loads are:

$$(Q_R R)_m = 300 \text{ kNm}, \; \sigma^2(Q_R R) = 1989 \text{ (kNm)}^2,$$

$$(Q_g M_g)_m = 90 \text{ kNm}, \; \sigma^2(Q_g M_g) = 162 \text{ (kNm)}^2,$$

$$(Q_q M_{q_s})_m = 18 \text{ kNm}, \; \sigma^2(Q_q M_{q_s}) = 162 \text{ (kNm)}^2,$$

$$(Q_q M_{q_e})_m = 28 \text{ kNm}, \; \sigma^2(Q_q M_{q_e}) = 784 \text{ (kNm)}^2.$$

The probability distribution of the conventional resistance of slabs by Equation (7) is close to the normal distribution. Mean and variance are:

$$R_{cm} = 300 - 90 - 18 = 192 \text{ kNm}, \; \sigma^2 R_c = 1989 + 162 + 162 = 2313 \text{ (kNm)}^2.$$

According to Equation (21), the conversional factor of truncated resistance distribution is equal to $\lambda = \varphi(-1{,}0812)/\Phi(1{,}0812) = 0{,}2585$. Thus, the revised statistical moments by (19) and (20) of the member resistance are:

$$R_{cr,m} = 192 + 0{,}2585(2313)^{1/2} = 204{,}43 \text{ kNm},$$

$$\sigma^2 R_{cr} = 2313[1 + 0{,}2585(-1{,}0812 - 0{,}2585)] = 1511{,}98 \text{ (kNm)}^2,$$

$$(\theta_R R)_k = 300(1 - 1.645 \times 0.1) = 250{,}65 \text{ kNm}.$$

Here $(\theta_R R)_k$ is characteristic resistance of slabs.

According to Equations (26)–(29), the statistical moments of design and inspection safety margins are:

$$Z_{km} = 300 - 90 - 18 - 28 = 164 \text{ kNm},$$

$$H_{km} = 250 - 90 - 18 - 140 = 2 \text{ kNm} > 0,$$

$$\sigma^2 Z = 1989 + 162 + 162 + 784 = 3097 \text{ (kNm)}^2,$$

$$\sigma^2 H_k = 1989 + 162 + 162 = 2313 \text{ (kNm)}^2.$$

According to Equations (30) and (31), the coefficient of correlation of these margins and the inspection instantaneous survival probability of the member are: $\rho_{ZH} = [2313/3097]^{1/2} = 0{,}864$ and $\boldsymbol{P}_{tr} = 0{,}522$. The extraordinary live bending moment M_{qe} is modeled by an exponential distribution. Thus the design value of instantaneous survival probability of slabs by Equation (10) is: $\boldsymbol{P}\{Z_k > 0\} = 0{,}99542$. It corresponds to the reliability index $\beta_k = \Phi^{-1}(P\{Z_k > 0\}) = 2.60$.

The revised values of instantaneous survival probabilities of slabs the analysis of whose was based on the concepts of truncated probability distribution and Bayes theorem are calculated respectively by Equations (22) and (32). They are equal to $\boldsymbol{P}_{rk1} = 0{,}99821$, $(\beta_{k1} = 2.91)$ and $\boldsymbol{P}_{rk2} = 0{,}99845$, $(\beta_{k2} = 2.96)$ respectively. The numerical integration and Bayes theorem methods gave the near values of survival probabilities. However, equation (32) may overestimate the revised reliability index of considered members (Fig. 3).

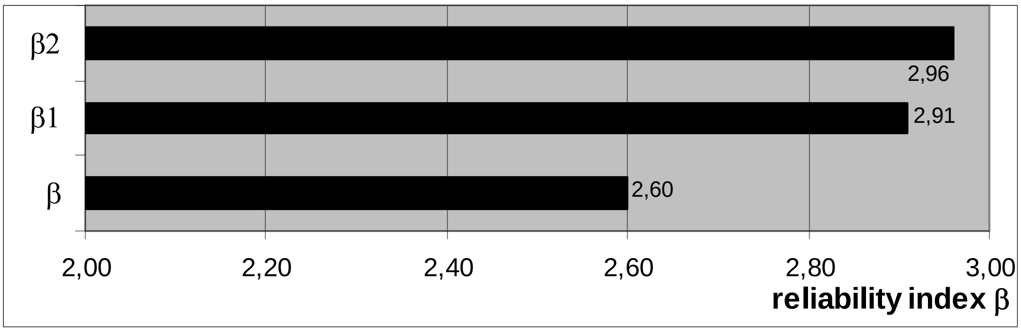

Figure 3. Instantaneous and revised reliability indexes of slabs.

7 CONCLUSIONS

The revised structural safety parameters of existing structures lead to correction of their technical service life and allow avoid both unexpected failures and unfounded premature repairs. However, it is rather difficult to revise objectively the design values of structural resistance and survival or failure probability of members and their systems. When unfavourable service-proven action effects caused by extreme live or climate actions are defined and confirmed by quality statistical information data, the revised safety parameters of structures may be assessed and predicted fairly exactly by presented engineering probabilistic approaches.

Generally, the extreme action effects of structures caused by service and climate loads are modeled as intermittent rectangular renewal pulse processes. Thus, the safety margins of particular members (sections, bars, connections) may be treated as random sequences. The revised values of instantaneous survival probabilities of particular members (sections, bars, connections) may be analyzed by Equations (22) and (32) based on concepts of their conventional resistance, truncated probability distribution and Bayes theorem approaches. These values may be successfully used in the prediction of long-term survival probabilities of members and systems during their residual service life using Equations (16) and (17) based on the concept of transformed conditional probabilities.

The presented approaches for revised probabilistic safety assessment and prediction of existing structures may be successfully used in engineering design practice.

REFERENCES

Allen, D. E. 1991. Limit state criteria for structural evaluation of existing buildings. *Canadian Journal of Civil Engineering*, No 18: 995-1004.

Ellingwood, B. R. 1996. Reliability-based condition assessment and LRFD for existing structures. *Structural Safety*, Vol 18, No 2/3: 67-70.

EN 1990:2002 E. *Eurocode – Basis of structural design*, Brussels, CEN.

Hong, H. P & Lind, N.C. 1996. Approximate reliability analysis using normal polynomial and simulation results. *Structural Safety*, Vol. 18, No 4: 329-339.

ISO 2394. 1998. *General principles on reliability for structures.* Switzerland.

JCSS. 2000. *Probabilistic model code: Part1-Basis on design.* Joint Committee on Structural Safety.

Kudzys, A. 2005. On account of concurrent rectangular pulse actions in structural design. *Advances in Safety and Reliability:* 1203-1206. London: Taylor & Francis.

Madsen, H. 1987. Model updating in reliability theory. *Proceedings /CASP5,* Vancouver, BC: 564-577.

Melchers, R. E. 1999. *Structural reliability analysis and prediction.* Chichester, John Wiley & Sons.

Mori, V. & Ellingwood, B. 1993. Reliability based service-life assessment of aging concrete structures. *Journal of Structural Engineering,* ASCE, Vol. 119, No 5: 1600-1621.

Rosowsky, D. & Ellingwood, B. 1992. Reliability of wood systems subjected to stochastic live loads. *Wood and Fiber Science*, Vol. 24, No 1: 47-59.

Stewart, M.G. & Rosowsky, D.V. 1996. System risk for multi-storey reinforced concrete building construction. *Probabilistic Mechanics and Structural Reliability*. Proceedings, ASCE, New York: 230-233.

Tang, W. H. 1973. Probabilistic updating in reliability analysis. *Journal of Testing and Education*, ASTM, Vol. 1, Nº 6: 459-467.

Trezos, C. G. & Thomos G. C. 2003. Reliability–based non-linear static analysis of reinforced concrete frames. *Concrete Structures in Seismic regions*, Proceedings of the fil Sympozium, Athens.

Vrowenvelder, A.C.V.M. 2002. Developments towards full probabilistic design codes. *Structural safety*, Vol. 24, No 2-4: 417-432.

A flexible and upgradeable facade concept for refurbishment

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ABSTRACT: A large percentage of offices in Europe is outdated on technical and design aspects. Different promising facade and climate concepts exist for new construction. The presented research aims to derive from these systems a high potential flexible and upgradeable façade concept suitable for renovation of office buildings. For a case study a concept has been developed which provides connections and installation space. Different levels and means of installations are just as possible as an easy change of cladding material or building physical standards. As such system can supply the necessary installations appropriate to every individual room it prevents the production and mounting of excessive components. Being upgradeable it combines the interests of sustainability and an economics to extend the life cycle of building stock.

1 INTRODUCTION

Two thirds of the office buildings in Europe are outdated. This means that façade and installations are older than 30 years (Russig). The average renovation interval for the interior is seven years. Design fashion changes rapidly. The supporting structure on the contrary can last very much longer. Dealing with a decreasing market for office real estate and thus falling rental rates, while user demands enlarge, building owners face the question of how to treat their office stock.

Demolition of technically good buildings leads to unnecessary waste, emission of CO2, energy consumption both in construction, as well as in form of grey energy bound in the material and processes. It also is a question of destruction of capital and on the social level a loss of architectonic identity in successively grown city centers.The research project “Systems in Façade refurbishment” aims to analyse common problems and to proof that renovation of offices can be a feasible solution helping to extend the life cycle of buildings.

2 DEMANDS FOR FAÇADES

To be able to deal with current and future demands for a building envelope one has to take many different aspects into account during the design process. Those aspects can be sorted into the categories: Architectural design, building construction, installation and financial aspects (Figure 01). The importance of economic aspects in the planning and design process is often underestimated, as ultimately, every concept has to prove it’s feasibility to be realized.

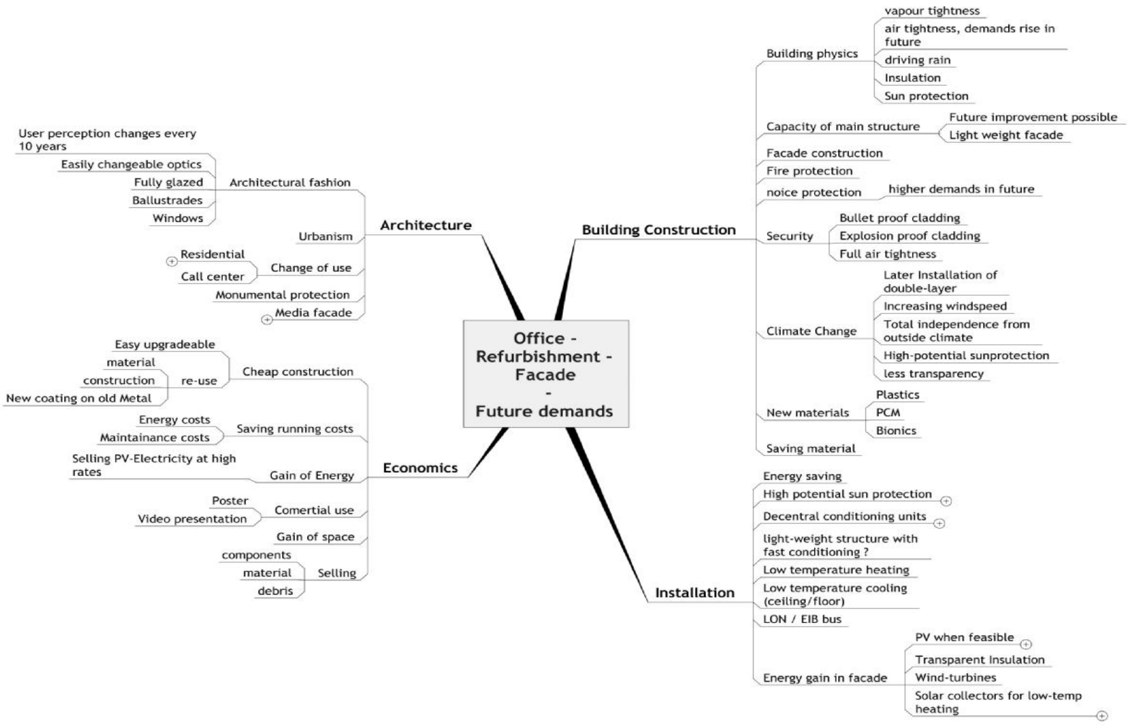

Figure 01: Overview of future demands for office facades

2.1 *Architectural design:*

- The architectural fashion is subject to constant change. To maintain a building, the outer appearance should be possible to be changed easily. New materials will provide properties and functions not yet known. Media installations may become a more important feature.
- On the contrary to constant change, more and more buildings are subject to monumental protection. In such case an upgrade may only take place without changing the outer appearance and will thus interfere with the interior.
- The use of the building may change. The tendency to work from home and not in a physical office, for example, already leads to an oversupply of office space. This situation will probably get worse in the future. To deal with it, the option to change the use of the building, e. g. to residential use, must be considered.

2.2 *Building construction*

- The supporting structure of a building limits the possibilities in façade renovation. Particularly steel structures are often not capable of extra loads. In such case the use of light weight materials can be considered.
- Fire protection has shown to be one of the biggest issues and motivations for renovation.
- While upgrading the façade all aspects of building physics, such as insulation, and vapour impermeability have to be brought to actual standards. A further future update should be kept possible.
- Global climate change will most likely cause a demand for future upgrade. While today's standards meet current needs, in the future higher temperatures, greater wind loads and stronger rainstorms are expected. (Stock)
- The requirements for security are likely to be higher in the future.

2.3 *Installations*

- Climate, electric and IT-installations are subject to constant development, thus a chance for upgrade must be provided to easily maintain or replace components. Furthermore the complete HVAC concept may be altered, e.g. to low temperature heating and cooling.
- The gain of energy within the façade is another topic of interest. Large surfaces of buildings can be equipped with PV or other means to produce energy which can be used or sold.
- Sun protection is most important in office buildings. Buildings with more than 55% of glassed surface tend to overheat (Hausladen) et al. Modern sun blinds installed outside prevent excessive heat input while allowing indirect natural lighting.
- Decentralized installations provide a large potential in renovation, as every need for ventilation and air condoning is met in the façade without the demand for ducts inside the building.
- The recent development in BUS systems makes control and maintenance of many data-points possible. Modern climate concepts demand a facility management system that allows for both individual and central control.
- The users' demands on their work environment change often. In northern Europe, for example people ask for individual climate control and operable windows for direct connection to the outside, while in other countries office staff relies more on central air conditioning.

2.4 *Economic aspects*

- The expense of building process and construction is only one part of the financial plan
- Re-use and re-cycling of material saves costs, selling of used material, is an option
- Very important for the users of a building are running and maintenance costs. With the introduction of the European Energy passport (EU) a tool is introduced which makes these costs more transparent to tenants and thus influences their decision for a property.
- Energy gained in the building envelope can be used or sold, often to very good conditions, depending on political guidelines.
- By renewing the façade and installation concept extra space can be gained due to smaller components or by transferring installation space into rental space by replacement of central air conditioning systems with decentralized façade-bound components.

3 LATEST DEVELOPMENTS IN FAÇADE CONCETS

3.1 *Service integrated façade systems*

Various façade system producers and architects have recently developed service integrated facades. These are composed of parts with fixed glazing, operable windows and decentralized HVAC service installations. In the development process facility managers, climate designers and the manufacturers of HVAC components are integrated.

Such systems are designed as element facades which can be installed in floor-high components. Decentralized heating-, cooling and ventilation units provide all necessary installations with minimized dimensions. They include mechanical ventilation with heat recovery and a heat exchanger for air conditioning. Air is taken in and brought out directly through the façade in every element. Thus no central mechanical ventilation and air ducts need to be installed.

Due to these short distances, such units provide a high efficiency in air conditioning and heat recovery. As every façade element is equipped with HVAC installations, it is easy to provide individual comfort control for every office space. Disadvantages of such systems lie in the lack of compatibility with operable windows and mainly in a large number of maintenance points like filters. A well administered facility management system is essential for this façade type. BUS installations with many data-points help solve the mentioned disadvantages. Two examples for modern, integrated façade systems are shown in Figure 2 (TEMotion) and Figure 3 (Capricorn):

Figure 02: Facade system TEMotion

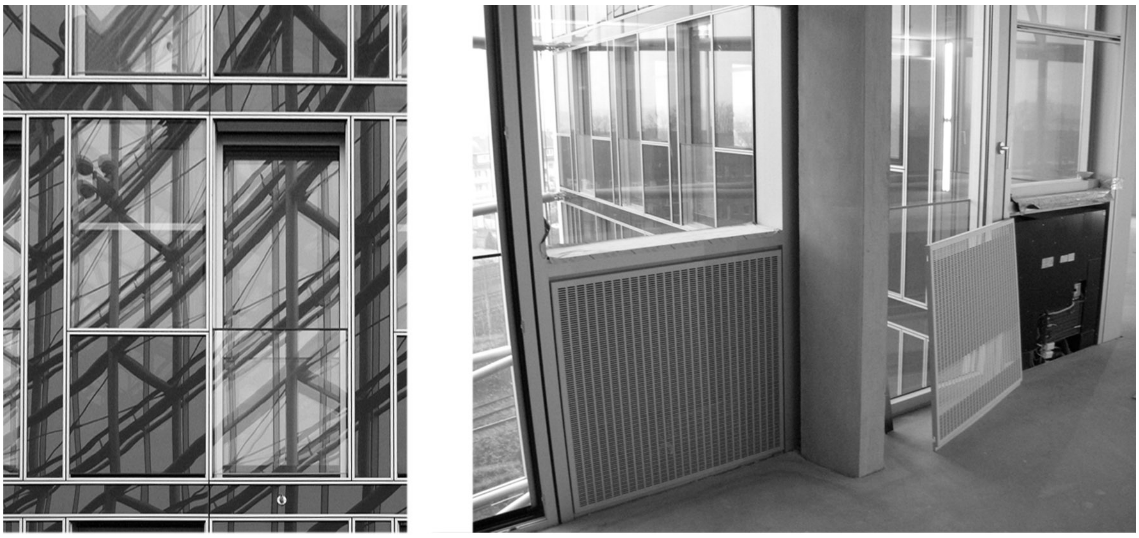

Figure 03: Facade system Capricorn building, Düsseldorf, Germany

3.2 *Fibre concrete façade, a development at University of applied science, Detmold, Germany*

Within the course program on glass construction a modular façade with integrated building services has been developed. This façade concept uses fibre reinforced concrete for the framework of the façade element.

The development of fibre reinforced concrete makes it possible to produce slim profiles and frames that have nearly the same dimensions as those manufactured from aluminium or steel. With such dimension the profiles are capable of carrying structural loads. Thus in a new construction of pre-fabricated elements this façade-concept makes load bearing columns redundant. At the end of the life span of a building made of prefabricated elements, the components, made from long-lasting material, can be re-used either directly or after being overworked in the factory.

The installation space provided within the façade element is dimensioned in a way that it can take in different installation components from a simple radiator heating up to an installation unit correspondent to those mentioned above. Operable windows provide natural ventilation, which, in northern Europe, makes mechanical ventilation unnecessary in spring and autumn.

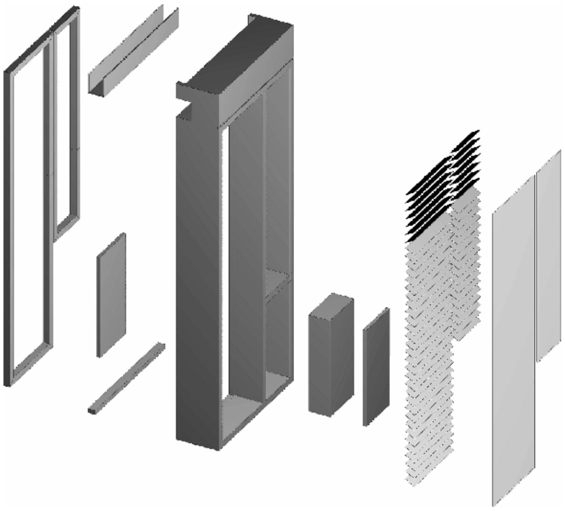

Figure 04: Fibre Reinforced façade module

4 THE REFURBISHMENT ENVELOPE THAT CHANGES WITH THE USE

All the service integrated façade systems on the market have been designed for new construction and thus plan to be equipped with complete installation units in minimized dimensions. For the task of refurbishment special matters have to be taken into account. During a case study analysis within the research program "Façade systems for refurbishment" at Delft Technical University a renovation façade concept has been developed which is suitable for renovation of different building types. Within the case study it has been designed for a building with concrete balustrades. This is reasonable, as fire regulations in Germany, where the case study building is located, demand a vertical barrier of one meter for high rise buildings.

The façade is composed of five components: A non transparent balustrade, a fixed glazing, an operable window, vertical connection elements and integrated space for installation units. For the case study the façade has been constructed as a ventilated façade, which can be cladded with different materials such as metal, glass, natural stone or wood panels. Further advantages of the ventilated façade lie in the flexibility for exchange of elements and insulation as well as in the good heat protection in summer due to the shading effect. The complete façade structure is mounted from the outside, which causes little interference with the interior. While connection details stay the same, the façade grid is adjustable both horizontally and vertically to different office grids.

Operable windows contribute to energy saving in spring and autumn. They provide the user with a desired connection to the outside and serve for maintenance and cleaning as the dimension of the fixed glazing permits to be reached from the window openings.

Horizontal adjustable sun blinds are installed outside the façade. These provide an efficient sun protection combined with relatively low costs and individual control. Depending on wind loads the installation of an additional glass pane for protection of the blinds can be considered.

Vertical connections between the floors of the building provide the option to install new tubing, electric cabling and IT installations within the façade. This prevents interference with the interior of the building, as no installations need to be installed in rooms or hallways. Existing installations can either continue to be used or set out of service depending on the climate concept. Old tubing can later be removed, when the next renovation of the interior is due. Horizontal distribution of media is realized within the balustrade space of the façade system. The installations are brought into the building either through the balustrade or at the connection points to vertical elements. Installation space is generously dimensioned to allow adding or replacing of ducts in the future.

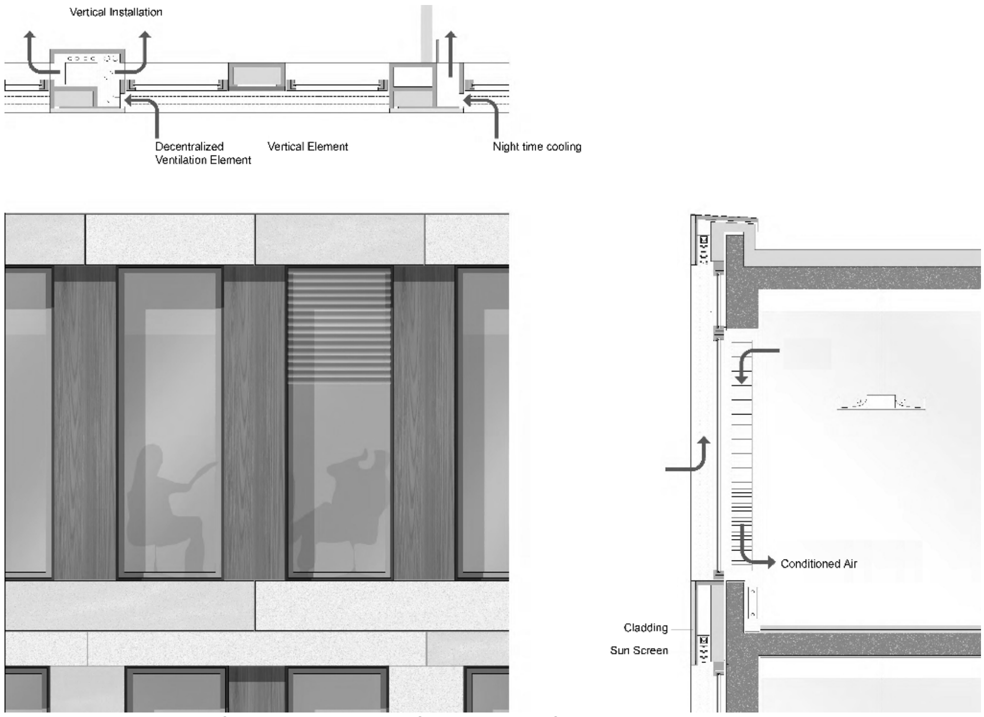

Figure 05: Concept for upgradeable refurbishment façade

The installation units integrated into the façade can be placed horizontally at balustrade level, where fire protection demands and given circumstances allow. Alternatively they can be installed vertically, in addition to or as a substitute for the connection elements.

The climate concept is based on the idea of de-centralized installations and full flexibility for upgrade and change. Following this, the installation "box" can be filled with different components or left empty. During the life cycle of the building different demands occur for different rooms (north- or south side; many electric appliances; high air exchange rates; etc.). With a flexible system rooms can individually and successively be up- or downgraded depending on the use. The following installation concepts are imaginable:

1. A minimal solution
   The building is equipped with high insulation and a ventilated façade. Thus it does not need any cooling and only minimal heating. Existing radiators (often installed in northern European office buildings) will be kept in use. Operable windows supply ventilation.
   This concept demands "smart users" able and willing to adjust their own office climate. Window contacts, thermostats and a central override control for heating and windows would allow saving energy or open designated windows for natural night time cooling.

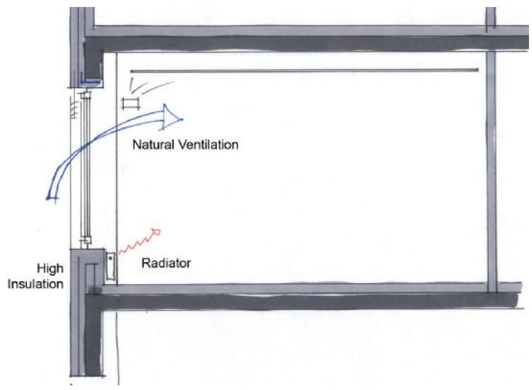

Figure 06: Minimal solution

2. Improved energy performance through heat exchangers
   As natural ventilation may lead to higher energy demands in extreme weather conditions (summer, winter, climate change) due to the direct exchange of air of different temperature levels, mechanical ventilation with heat recovery is a common option. Small individual ventilation units can be installed in the climate-boxes and thus provide fresh air without the loss of thermal energy. Such small decentralized fans with heat exchanger provide a high efficiency, as no ducts are needed to transport conditioned air.

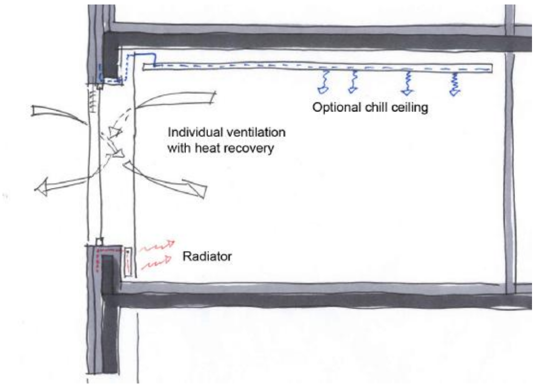

Figure 07: Improvement by heat exchanger

3. The all-in-one solution
   Climate installation devices which provide ventilation with heat recovery and air conditioning by heat exchangers can be placed into the installation space provided. These are connected to hot water and cooling liquid circuits, are controlled individually and provide full climate conditioning with a high efficiency. This is due to direct air supply through the façade and small, energy efficient fans.

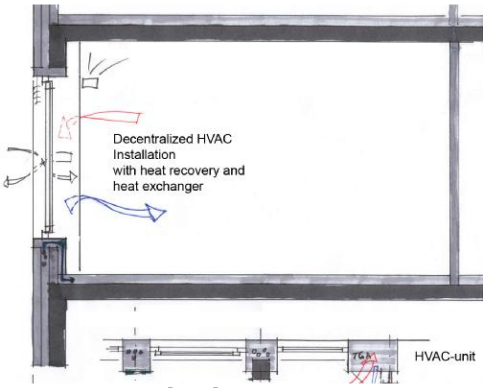

Figure 08: Decentralized HVAC units

4. Low temperature heating/cooling
   Alternatively to active air conditioning, the installation of low temperature systems can be considered. A chill ceiling provides comfortable cooling in summer by transporting water of a temperature slightly below room temperature through small tubes within a suspended ceiling. In a highly insulated office building heating is only rarely necessary, thus the ceiling can also be used for heating in winter. For a surface heating the temperature of the water only needs to be around 25 °C instead of the 70°C hot water needed for radiator heating. The changing of the climate installations to such a low temperature system makes the old machinery redundant and opens the field for sustainable solutions. The desired temperature level can e.g. be reached by geo thermal energy and heat pumps.

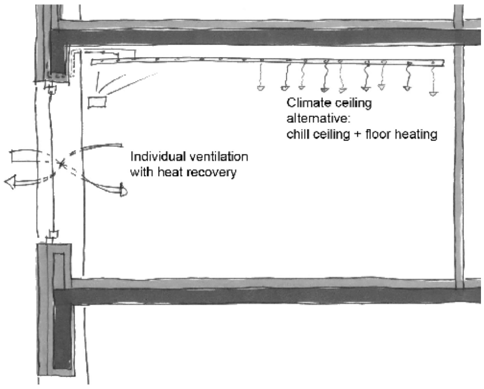

Figure 09: Low temperature heating and cooling

As long as installation space is provided and easily accessible changing of installations can be done with minimal interference with running work. An important task not yet solved lies in the easy possibility to combine and connect components. While electric and IT installations are equipped with common connectors, the topic of easy (de-) connection of water-, heating and cooling liquid tubing is new in the building process.

For future buildings it is imagined to be an interesting marketing concept to offer "Facades for rent". Users rent façade components or installation parts according to their need. When they are not needed any more, the supplier takes them back into stock to rent them out to other clients. This extends not only they life cycle of the building, but also the one of every component and prevents an overproduction.

5 SUMMARY AND CONCLUSION

There is a big market for refurbishment of office buildings. Many interesting façade systems and components are already available for new construction. To transfer those for the task of renovation, various special aspects have to be taken into account. New developments particularly have to deal with the demands of the user and a big flexibility in construction, installation and design. To achieve flexibility and upgradeability of the building envelope a standard is needed for dimension and connection of various installation components. New business-concepts may turn up in which a tenant of a building can rent installation components to be installed into his façade system according to his needs and return them for re-use. New materials and technical innovations will contribute to more sustainable and material saving constructions.

Finally it can be concluded, that refurbishment of office buildings by means of smart façade and installation concepts extends the life span of buildings significantly and thus supports both feasibility and sustainability.

6 REFERENCES

EU directive 2002/91/EC on energy performance of buildings

Hausladen, G. et al. 2006. *Clima Skin*. Munich: Callwey

Russig, V. 1999. *Gebäudebestand in Westeuropa*, Munich: IFO Schnelldienst

Stock, M. (Ed.). 2005). *PIK Report No.99: KLARA - Klimawandel - Auswirkungen, Risiken, Anpassung.* Potsdam: PIK

Performance based design using life cycle cost analysis

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ABSTRACT: Life cycle cost analyses is one of the useful tool for evaluating the lifespan performance of buildings. The sum of initial and future costs associated with the construction and operation of a building over a period of life time is determined by life cycle cost analysis. In this study, a moment-resisting steel building is designed using various base shear values and the life cycle cost of each design is determined for different earthquake intensities. Static pushover analysis is used to calculate yield base shear value of each design and initial costs, the cost of the expected damages caused by earthquakes that are expected to occur during the design life of the buildings are estimated. The optimum economic design of the steel building is determined by using yield base shear and total cost values.

1 INTRODUCTIONS

Kocaeli and Düzce Earthquakes (1999) in Turkey caused significant damage to buildings, public facilities, infrastructures and many casualties. In these catastrophic earthquakes, number of loses in terms of human lives and economic loses were too high. There were 18,373 accounted deaths and 48,901 injuries (Erdik, 2000). If it is assumed that the indirect social economic loses should be about as much as the direct physical loses, the total economic lost were in the vicinity of US$ 16 billions. Also, the economic loses of the buildings were approximately about US$ 5 billions. In the view of the large damage suffered in these earthquakes, the Turkish Earthquake Resistant Design Code is improved to protect life and reduce damage to an acceptable level.

Structural behavior and performance under a given earthquake loading, risk and probability must be considered when defining adequate design criteria. The costs and loses from possible future earthquakes and the difficulty in repairing the post earthquake damage, suggest the need for consideration of damage control in the design rather than just for life loss prevention. This can be taken into account by the development of design criteria which balances the initial cost of the building with the expected potential loses from future earthquake damages.

In building construction, primary concerns are design of the building, construction technique and building construction cost. These significant concerns are not the only concerns that should be addressed when planning for the future. In order to investigate the economics of facility management, the cost of building operations over the life of a building should be taken into account as well. The sum of initial and future costs associated with the construction and operation of a building over a period of life time is determined by using life cycle cost analysis.

The aim of this study is to determine the optimum design base shear value using life cycle cost analysis. For this purpose, a moment-resisting steel building is designed by using various base shear values. Initial costs, the cost of the damages and the total life cycle costs are estimated. The optimum economic design of the building is obtained using yield base shear and total cost values.

2 PERFORMANCE BASED DESIGN

Performance based building design is a general structural design philosophy in which the design criteria is chosen with respect to the selected performance level under various seismic motions. The important aim of the contemporary seismic design is not only protecting the human life but also accounting the additional performance targets. The advances in computer technology within the last decades made possible to employ more complex and realistic design procedures based on nonlinear analysis instead of conventional linear analysis.

Performance based design concepts have been introduced by various guidelines such as SEAOC Vision 2000 (1995), ATC-40 (1996), FEMA-356 (2000), FEMA-440 (2005). The main objective is to increase the safety against earthquakes to make them having a predictable and reliable performance. There are various types of analysis methods for assessing the structural performance level of buildings. Guidelines generally suggest the use of linear static, nonlinear static, linear dynamic, and nonlinear dynamic analysis procedures. However, the most popular analysis method is the nonlinear static analysis which is also known as pushover analysis. Pushover analysis is very efficient method for the direct evaluation of the structural performance at each limit-state.

The aim of the pushover analysis is to assess the structural performance in terms of strength and deformation capacity. Pushover analysis is based on the assumption that the response of the building is related to the response of an equivalent single degree of freedom system with properties proportional to the fundamental mode of the building. Using the analysis results, the sequence of member yielding, inelastic deformation amount of critical members, maximum interstorey drifts and the possible collapse mechanisms of the building can be identified.

The pushover analysis starts after application of gravity loads. A lateral load distribution is generally chosen proportional to the fundamental mode of the building. The building model is pushed using the predefined fixed lateral load pattern and total lateral load is incremented up to the lateral displacement of the control node reaches to the displacement demand of the selected earthquake level. The displacement demand of earthquake which is also called as the target displacement can be obtained from the FEMA-356 (2000) formula depending on the performance level considered.

$$\delta_t = C_0 \, C_1 \, C_2 \, C_3 \, S_a \frac{T_e^2}{4\pi^2} g \tag{1}$$

where T_e is the effective fundamental period of the building in the direction under consideration; S_a is the response spectrum acceleration corresponding to the T_e period, normalized by g; C_0 C_1 C_2 C_3 are modification coefficients of displacement demand of earthquake.

The pushover curve, which is obtained with the end of the pushover analysis, is converted to a bilinear curve with a horizontal post-yield branch that balances the area below and above the pushover curve and the yield base shear of building is determined.

Using a single fundamental mode dominated load pattern in a pushover analysis may provide satisfactory estimation of the maximum interstorey drift when it occurs at the lower storey levels for regular buildings. When the maximum interstorey drift occurs at upper storey levels where higher mode contributions are significant, errors may become very large. In last years, some extensions to account for higher mode effects have been proposed and contributions to pushover procedures are still an ongoing research process (Aydinoglu, 2003; Chopra & Gupta, 2002).

3 EVALUATION OF LIFE CYCLE COST

The life cycle cost of a steel building can be considered as the sum of many different cost components. Cost of planning and design, cost of structural materials, cost of fabrication such as connection of members, cost of transporting fabricated pieces to the construction field, cost of handling, storage costs of rolled sections are basic initial costs. Erection cost, cost of tool operations and machinery on the construction site, cost of preparing the project site including the cost of preparing the foundations are also parts of the initial cost functions. In general, initial cost functions depend on the design intensity. The nonstructural component costs, such as those of partitioning, which may be high but do not depend on design intensity, were therefore, generally not considered as initial cost components.

There are other cost components which are generally accounted in life cycle cost calculations. Maintenance cost such as painting of exposed members of a steel building, inspection cost to prevent a potentially major damage to the building, repair cost, operating cost required for proper functional use of the building such as heating and electricity, damage cost based on an acceptable probability of failure, demolishing costs are some of the other cost components beside the initial costs.

In recent years, the limit state cost functions which is also an important part of the life cycle cost analysis have gained importance. The term limit state cost functions consists of the potential damage cost from earthquakes that may occur during the lifespan of the building. Limit state cost functions neglects other expenses which are not related to earthquake damages, such as maintenance costs. The limit state dependent cost functions mainly consists of damage cost, loss of contents, relocation cost, economic loss which is sum of rental and income loss, cost of injury, and cost of human fatality, and other direct or indirect economic losses. FEMA 255 (1994), FEMA 256 (1994) and ATC-13 (1985) can be used in limit state dependent cost functions calculations. In the present paper, evaluation of the damage cost due to earthquake occurrence is mainly focused and other cost components are neglected in order to monitor the damage cost effect on the life cycle cost.

The expected life cycle cost function under a single hazard can be calculated by the formula given below (Wen & Kang, 2001a):

$$E[C(t,x)] = C_0 + (C_1P_1 + C_2P_2 + ... + C_kP_k)\frac{\upsilon}{\lambda}\left(1 - e^{-\lambda t}\right) \tag{2}$$

where; P_k is the probability of the k^{th} damage state being violated given the earthquake occurrence and C_k is the corresponding cost; C_0 is the initial cost; λ is the annual momentary discount rate considered to be constant; υ the annual occurrence rate of significant earthquakes; and t is the service life of a building.

Damage states are defined according to the maximum interstorey drift of a building and limit values of each damage state is listed in Table 1 (Wen & Kang, 2001b). The cost of each damage state is described as a percentage of the initial cost and shown in the same table as well.

Table 1. Performance Levels and Damage Costs of a Building in Terms of Interstorey Drift Ratio*

Performance Level	Damage State	Interstorey Drift Ratio (%)	Cost % of Initial Cost
I	None	Δ<0.2	0
II	Slight	0.2<Δ<0.5	0.5
III	Light	0.5<Δ<0.7	5
IV	Moderate	0.7<Δ<1.5	20
V	Heavy	1.5<Δ<2.5	45
VI	Major	2.5<Δ<5	80
VII	Destroyed	Δ<5	100

*ATC-13 (1985)

The probability of each damage state is calculated with the following equation:

$$P_i = P_i(\Delta > \Delta_i) - P_{i+1}(\Delta > \Delta_{i+1}) \tag{3}$$

According to Poisson's law, the annual probability of exceedance of an earthquake is given by the formula (Wen, 2001):

$$P_i(\Delta > \Delta_i) = (-1/t)\ln\left(1 - \overline{P}_i(\Delta > \Delta_i)\right) \tag{4}$$

where is the annual exceedance probability of the maximum interstorey drift value Δ_i.
The annual exceedance probability of the i^{th} damage state is obtained as:

$$\overline{P}_i(\Delta - \Delta_i) = a\, e^{-b\Delta_i} \qquad (5)$$

The parameters a and b are obtained by best fit of known pairs. These pairs correspond to the earthquakes which probability of exceedance in 50 years is 2%, 10%, and 50%, respectively.

4 NUMERICAL EXAMPLE

A five storey moment resisting steel frame office building with the base area dimensions of 30.00 m x 24.00 m and 3.00 m storey height is considered. The structural model of the building is shown in Figure 1. The frame sections used for the designs of the steel buildings are limited with IPE and HEB profiles. Beams of floors are chosen from IPE profiles and all the beams of one floor are assumed to have the same type of section. However, columns are chosen from HEB profiles and all the columns of one storey is assumed to be designed with the same type of section as seen in Table 2. All members of the steel buildings are designed by using TS 648 and Turkish Earthquake Resistant Design Code. The modulus of elasticity is equal to E= 210000 MPa and the yield stress is f_y= 235 MPa. Steel frames are assumed to have rigid connections and fixed supports. Reinforced concrete is used in floor slabs and live loads are taken as 2.00 kN/m^2.

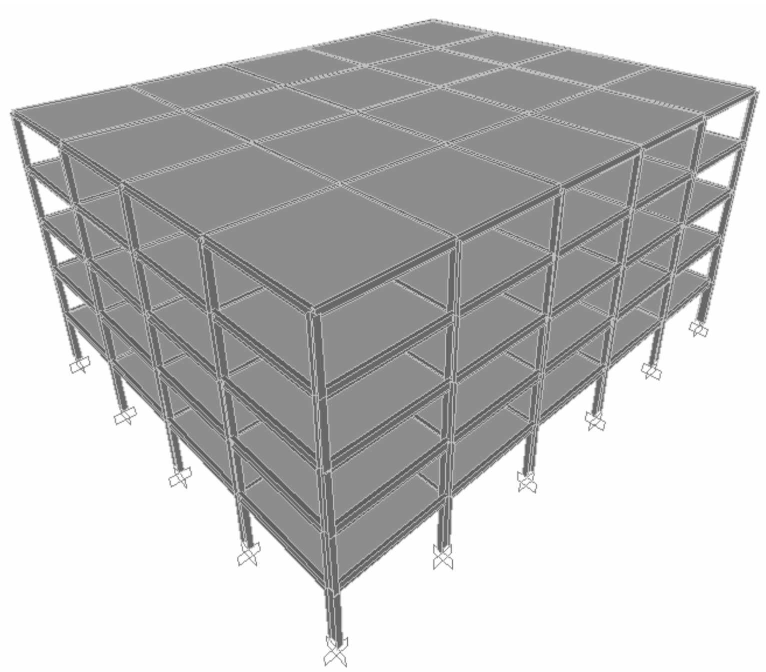

Figure 1. Five storey steel building

Table 2. Beam and column sections of designed steel buildings

Storey	Type	Design1	Design2	Design3	Design4	Design5
5	Column	HEB200	HEB200	HEB220	HEB240	HEB260
	Beam	IPE360	IPE360	IPE360	IPE360	IPE360
4	Column	HEB200	HEB220	HEB220	HEB240	HEB280
	Beam	IPE360	IPE360	IPE360	IPE360	IPE360
3	Column	HEB220	HEB220	HEB240	HEB280	HEB340
	Beam	IPE360	IPE360	IPE360	IPE360	IPE400
2	Column	HEB240	HEB240	HEB260	HEB300	HEB400
	Beam	IPE360	IPE360	IPE360	IPE360	IPE450
1	Column	HEB260	HEB260	HEB260	HEB320	HEB450
	Beam	IPE360	IPE360	IPE360	IPE360	IPE450

Table 2. Beam and column sections of designed steel buildings (Continue)

Storey	Type	Design6	Design7	Design8	Design9
5	Column	HEB300	HEB300	HEB320	HEB360
	Beam	IPE360	IPE360	IPE360	IPE360
4	Column	HEB300	HEB340	HEB400	HEB500
	Beam	IPE360	IPE400	IPE450	IPE500
3	Column	HEB400	HEB500	HEB650	HEB700
	Beam	IPE450	IPE450	IPE500	IPE550
2	Column	HEB450	HEB600	HEB700	HEB900
	Beam	IPE500	IPE500	IPE600	IPE600
1	Column	HEB500	HEB600	HEB700	HEB900
	Beam	IPE500	IPE500	IPE600	IPE600

In pushover analysis, Sap2000 (2006) is used and the lateral load distribution is chosen proportional to the fundamental mode of the buildings. Total lateral load is incremented up to lateral displacement of control node reach to the displacement demand of the selected earthquake level. The pushover curves converted to bilinear curves with a horizontal post-yield branch that balances the area below and above the pushover curves and then the yield base shear of buildings are obtained. The displacement demand of earthquake which is also called as target displacement is obtained from the FEMA-356 (2000) equations.

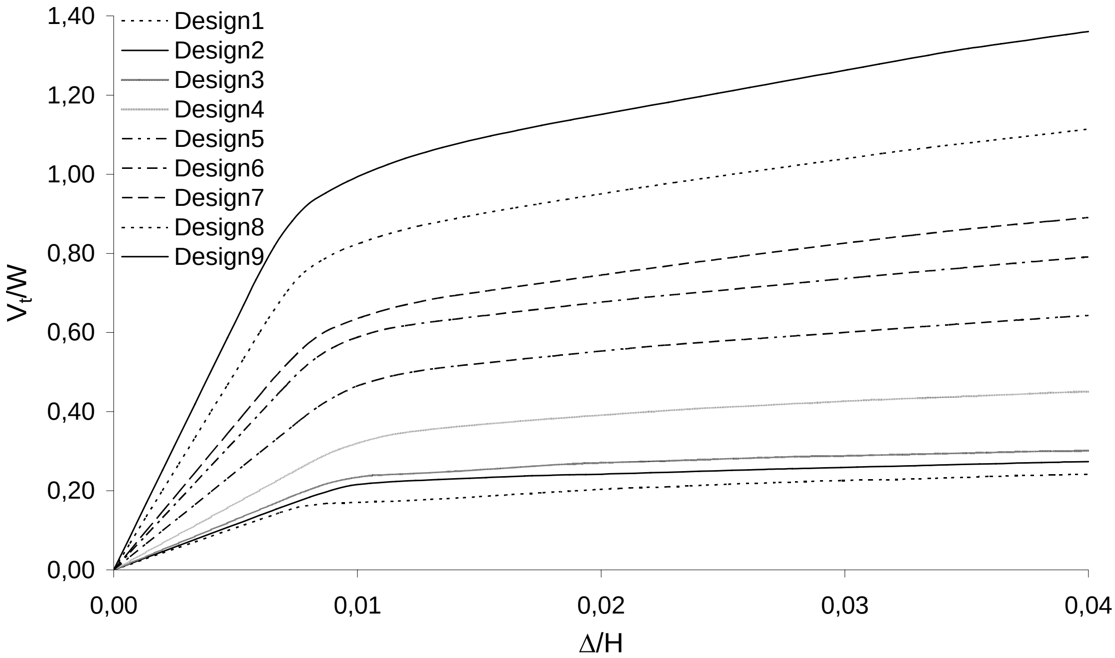

Figure 2. Static pushover curves of steel buildings

The calculation of the life cycle cost function for each design is also determined separately. The life cycle cost function calculation steps are given in details for the Building Design 6 in order to show the procedure clearly. From pushover analysis, three pairs of maximum interstorey drift are obtained and the annual probability of exceedance of an earthquake with a probability of exceedance %2, %10 and %50 in 50 years are calculated as $\overline{P}_{2\%} = 0{,}000404$, $\overline{P}_{10\%} = 0{,}0021$, $\overline{P}_{50\%} = 0{,}0139$. Using the maximum interstorey drifts and annual probability of exceedance values, $\left(\Delta_i - \overline{P}_i\right)$ pairs correspond to the three hazard levels with the given annual probabilities of exceedance is used to obtain the curve by an exponential function which is fitted by performing regression analysis. Once the function of the curve is plotted, annual probabilities of exceedance for seven damage states can be interpolated easily by using Figure 6. The values can be substituted to Equation 2 to calculate the values of life cycle cost functions.

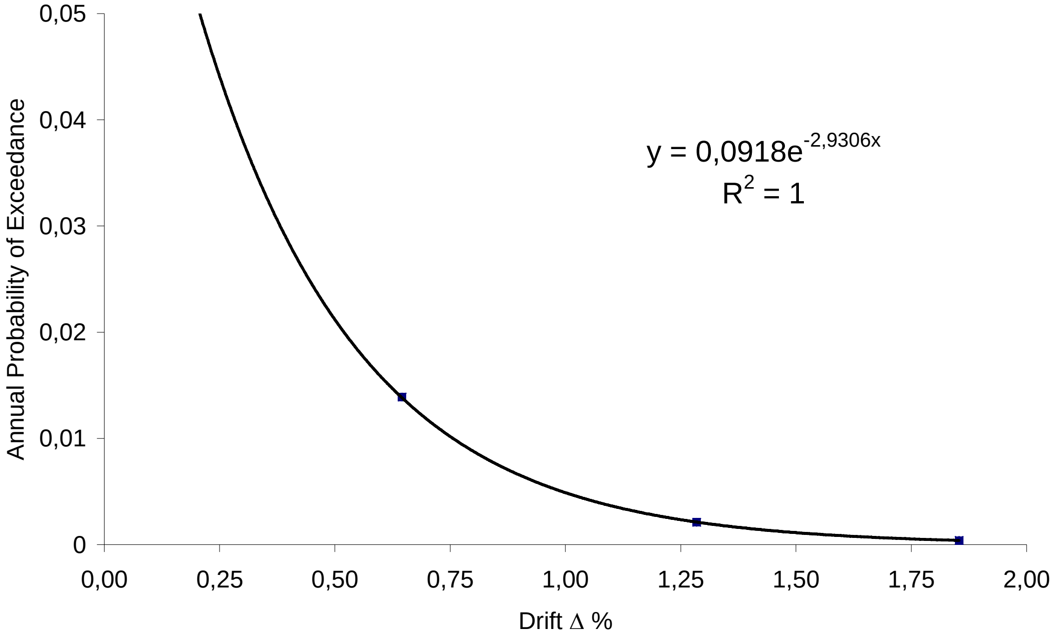

Figure 3. Calculation of annual probability of exceedance for each damage state design (Design 6)

Total expected damage cost is equal to the sum of the cost functions multiplied by the corresponding limit state probabilities. The optimal system yield force coefficient S_y can be calculated as the ratio of yield base shear force over weight of the building. A polynomial is used to fit the cost function and the optimal point for the life cycle cost is determined. The optimal system yield force coefficient S_y is found to be approximately 0.30 without considering human injury and death as shown in Figure 4.

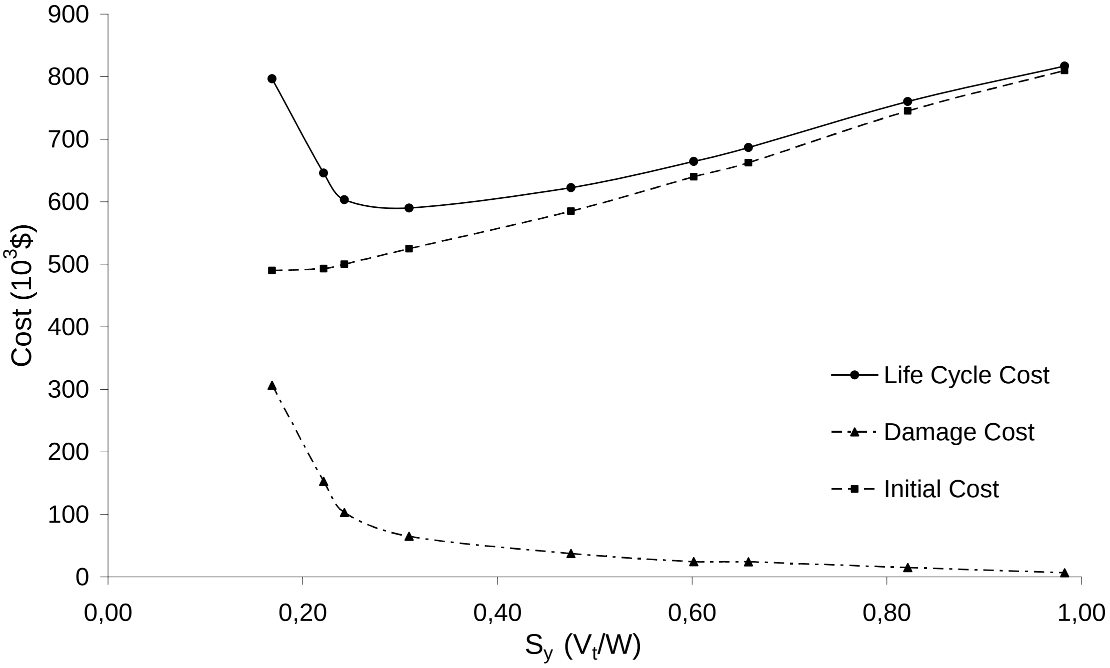

Figure 4. Total expected life cycle cost as a function of system yield force coefficient

5 CONCLUSIONS

The performance based design of steel buildings using life cycle cost analysis is investigated. Static pushover analysis performed during the cost analysis phase to determine the level of damage for different earthquake intensities. The cost analysis is based on initial material weight and earthquake induced life cycle cost. For the numerical example a five storey moment resisting steel office building is designed with various base shear values. Initial costs and damage costs are calculated in order to monitor the life cycle costs. The optimal system yield force coefficient is found to be approximately 0.30 using life cycle cost analysis. When the structural design is performed with single objective of minimizing the material weight, the resulting design will may be easily damaged with future earthquakes leading to much higher cost during the lifetime of the building.

REFERENCES

ATC–13. 1985. *Earthquake damage evaluation data for California*. Applied Technology Council. Redwood City. California.

ATC–40. 1996. *Seismic evaluation and retrofit of concrete buildings*. Applied Technology Council. Redwood City. California.

Aydınoğlu, M.N. 2003. An incremental response spectrum analysis procedure based on inelastic spectral displacements for multi-mode seismic performance evaluation. *Bulletin of Earthquake Engineering*. 1:1–34.

Chopra, A.K. & Goel, R.K. 2002. A modal pushover analysis procedure for estimating seismic demands for buildings. *Earthquake Engineering and Structural Dynamics*. 31:561–582.

Erdik, M. 2000. *Report on 1999 Kocaeli and Düzce (Turkey) Earthquakes*. Department of Earthquake Engineering. Bogazici University.
Available: http://www.koeri.boun.edu.tr/depremmuh/eqspecials/kocaeli/Kocaelireport.pdf

FEMA–255. 1994. Seismic *rehabilitation of federal buildings: A benefit/cost model Volume 1: A user's manual*. Federal Emergency Management Agency. Washington DC.

FEMA–256. 1994. *Seismic rehabilitation of federal buildings: A benefit/cost model Volume 2: Supporting documentation*. Federal Emergency Management Agency. Washington DC. USA.

FEMA–356. 2000. *Prestandard and commentary for seismic rehabilitation of buildings, Federal Emergency Management Agency*. Washington DC. USA.

FEMA–440. 2000. *Improvement of nonlinear static seismic analysis procedures*. Federal Emergency Management Agency, Washington DC. USA.

Sap2000. 2006. *Linear and nonlinear static and dynamic analysis of three-dimensional structures*. CSI Computers & Structural, Inc. Berkeley. California. USA.

SEAOC Vision 2000. 1995. *A framework of performance-based seismic engineering of buildings*. Structural Engineers Association of California. Sacramento California. USA.

TS648. 1980. *Building Code for Steel Structures*. Turkish Standard Institute. Ankara. Turkey.

TERDC. 2007. *Turkish Earthquake Resistant Design Code*. The Ministry of Public Works and Settlement. Ankara. Turkey.

Wen, Y.K. 2001. Minimum lifecycle cost design under multiple hazards. *Reliability Engineering and System Safety*. 73:223–231.

Wen, Y.K. & Kang, Y.J. 2001a. Minimum building life-cycle cost design criteria I: methodology. *Journal of Structural Engineering*. ASCE. 127(3):330–337.

Wen, Y.K. & Kang, Y.J. 2001b. Minimum building life-cycle cost design criteria II: applications. *Journal of Structural Engineering*. ASCE. 127(3):338–346.

Hygrothermal profiles of building elements in the context of service life design

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ABSTRACT: Moisture in building elements is closely related to the building's service life duration and overall performance. A building's service life design aiming at predicting and improving the building's performance during its lifetime should take into account the hygrothermal performance of the building's elements. In this context, a study of the hygrothermal performance of buildings components in Greece is conducted. The building elements under study are outer wall constructions. Each construction is analyzed for four orientations (N, S, W, E) and for the climate of Thessaloniki. The heat and moisture transfer in the building's components is analyzed with the use of the simulation software WUFI Pro4.0. The climatic data used for the analysis with WUFI Pro-4.0 are obtained with the use of a version of the computer program METEONORM. The resultant hygrothermal profiles, as well as some other data relative to the walls' hygrothermal performance are compared for the various cases.

1 INTRODUCTION

The implementation of sustainability principles in construction industry and practice has been the objective of many actions undertaken since the last decades of the previous century. Sustainability in construction is related to every aspect and stage of a construction's life cycle. Issues such as the materials used, the construction techniques employed, the consumption of energy, water and other resources during the construction's lifetime are now revisited in the context of a more sustainable approach. Among these issues one that is important is the need for maintenance, repair and replacement of construction elements and components. Indeed, the maintenance, repair and replacement of construction elements are closely related to the construction's sustainability, since they are coupled to the resources consumption (materials, energy, etc.) during the construction's lifetime and to the multi-level cost resulting from an interruption, even a short one, of the construction's function.

A reliable assessment of a construction's components' needs for maintenance and repair involves, among others, the identification of the deterioration mechanisms and of the factors that determine the rate of the construction materials' and components' degradation processes. For an impressive number of materials' degradation processes and construction components' destruction types, the water in the construction (as a result of vapor condensation, rain absorption, underground water uptake etc.) is a major factor of influence. In fact, the water in a component can act either as the direct aggressive agent or indirectly, accelerating or facilitating the progress of various destructive procedures (Fagerlund 1996). The deterioration processes in the context of which water acts directly are numerous. Freeze thawing cycles (frost attack), mould growth on the surface of various materials (mainly on wood), loss of bond between two materials in a component due to the accumulation of moisture at the interface are only few of the component destruction processes that belong to this category. Examples of the indirect contribution of water in destruction mechanisms of construction components are chemical attacks on natural stones, reinforcement corrosion in concrete elements (carbonation of the concrete cover, diffusion of chlorides into and through the concrete cover, initiation and propagation of the bars' corrosion) etc. Finally, the two types of water's action can coexist in a construction component or material. For example, a concrete element is submitted to many types of degradation mechanisms, the majority of which are somehow influenced by moisture's presence, accumulation or fluctuation in its mass (Rendell et al. 2002), (Neville 1995), (Lea et al. 1998).

It is therefore obvious that the prediction of a construction component's service life and of its needs for maintenance and repair involves, among other things, the analysis of its hygrothermal performance. In the following paper, a study of the hygrothermal performance of buildings' outer wall constructions is conducted for the four basic orientations (South, North, West, East) for the climate of Thessaloniki, a city in northern Greece. The wall constructions under study are considered to be representative of the current building construction practice in Greece. The results are discussed in the context of the potential damage that could result from the components' hygrothermal performance. Comparisons of the results for the various cases of outer wall constructions and the four orientations are made.

2 SOFTWARE USED FOR THE ASSESSMENT

2.1 *Introductive discussion*

During the last decades, the increased interest for the building components' hygrothermal performance has led to the development of numerous methods (and the corresponding tools) for the analysis of the processes related to heat and moisture transfer through and inside building elements. These methods vary greatly in what concerns the formulation of the mathematical model they use to simulate the physical processes (driving potentials etc.) and the assumptions and simplifications they employ. Such assumptions and simplifications usually concern the consideration or not of the materials' properties dependence on their water content and on the levels of temperature in their mass, the inclusion in the model or not of various transfer mechanisms and phenomena (e.g. convection, latent heat of phase change etc.) the dimensions of the analysis (1-d, 2-d, 3-d), etc. For example, there are tools that perform a one dimensional analysis of the heat and moisture transfer processes in building elements. (1-D hygIRC, WUFI pro-4.0, MOIST 3.0, GLASTA, 1-D HAM (Hagentoft et al. 2000), MATCH, etc.) and others that extend to two dimensions (WUFI StOpStar, Latenite-VTT (Geving et al. 1997), etc.). An extensive overview of building components' hygrothermal performance analysis tools can be found in (Canada Mortgage and Housing Corporation).

The tool used for the elements' hygrothermal performance analysis in this study is WUFI pro-4.0. The climatic data that are used as input for WUFI are generated with the use of the computer program METEONORM. In the following paragraphs there is a short description of those two PC programs.

2.2 *Tool for the analysis of moisture and heat transport inside building components*

WUFI pro-4.0 is a program for the one dimensional analysis of the heat and moisture transport through and inside building components. The physical background of WUFI, as well as the numerical treatment of the mathematical formulations used for the calculation of the phenomena under study can be found in (Künzel 1994). WUFI's results are in agreement with measurements in constructions (Künzel 1994).

WUFI calculates the simultaneous transient heat and moisture transport through and inside building elements by solving a set of coupled partial differential equations. In order to solve this set of equations, a set of boundary and initial conditions is required. The heat transport mechanisms that are taken into account in WUFI are the thermal conduction, the enthalpy flows through moisture movement with phase change, the short-wave solar radiation and the nighttime long-wave radiation cooling (only when a certain type of climatic data file is used, TRY files). The vapor transport mechanisms that are taken into account in WUFI are vapor diffusion and solution diffusion, while in the calculation of liquid water transport, WUFI includes the mechanisms of capillary conduction and surface diffusion. The convective transport of heat and vapor by air flows is not included in the analysis conducted by WUFI. The results one can get from WUFI are of various kinds and give a complete and detailed picture of the component's performance. A detailed description of the results one can get from WUFI pro-4.0, as well as on other issues concerning the program can be found in the software's manual.

The material data that are needed as input for WUFI include, apart from the basic material data (density, porosity, thermal conductivity, heat capacity and water vapor diffusion resistance factor), a set of material data that are related to the heat and moisture transport processes.

The distributions of heat and moisture in the building component depend, among others, on the conditions in the surrounding. In order to take into account the conditions in the surrounding, weather files for indoor and outdoor environment are required. The climatic data may be either measured or synthetic. There are various types of weather files that can be used within WUFI. In the analysis for the present study, a TRY type file was used, generated with the use of METEONORM 5.0.

2.3 *Tool for the generation of climatic data*

METEONORM is a computer program that can be used for climatological calculations and as a data source for various programs. It is also a meteorological database, containing data for solar applications. Requiring only a few information about the site (altitude, longitude, latitude, type of site, etc.), it can provide a complete set of hourly or monthly climatic data that can be used in various analyses. Apart from defining a site by giving simple information, the user has also the possibility to select a site from a catalogue containing 6 types of sites: cities, weather stations, design reference years, sites with imported monthly values, sites with imported hourly values and WMO/OMM stations. METEONORM can provide hourly climatic data in various types of files, so that they can be used by various PC programs.

3 ASSESSMENTS

3.1 *Wall constructions assessed and materials used.*

The wall constructions assessed are considered by the authors to be representative of the current construction building practice in Greece. These constructions are illustrated in Figure 1. The constructions are named Case A, Case B, Case C, Case D, and this is how they will be referred to from this point on. For all the constructions, the outdoor environment is considered to be on the left and the outdoor on the right.

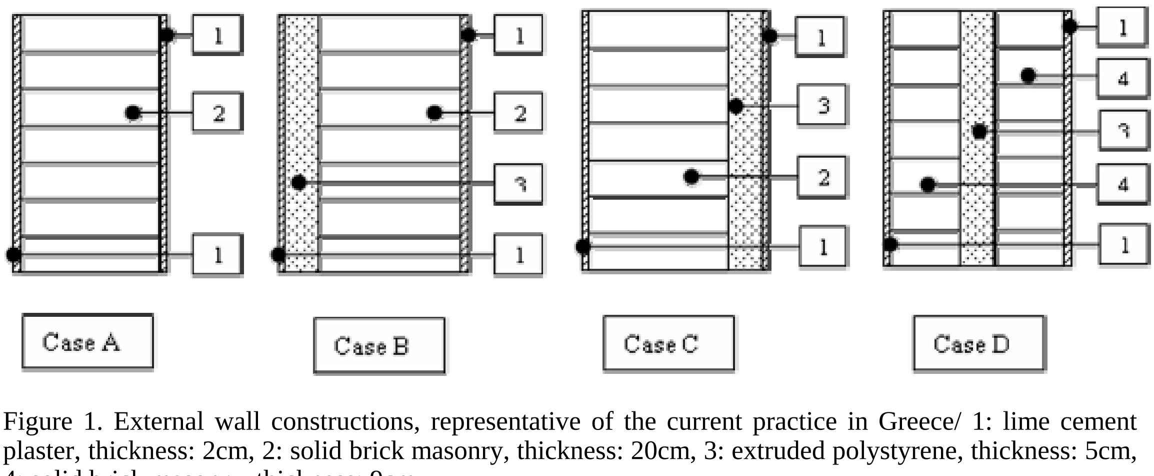

Figure 1. External wall constructions, representative of the current practice in Greece/ 1: lime cement plaster, thickness: 2cm, 2: solid brick masonry, thickness: 20cm, 3: extruded polystyrene, thickness: 5cm, 4: solid brick masonry, thickness: 9cm.

The basic idea being the analysis of the hygrothermal performance of outer wall constructions that are considered to be representative of the current practice in Greece, the materials chosen were the ones that are thought to be closer to the current practice. Since there are not any extended studies concerning the whole of the material properties, that are needed as input for WUFI-pro 4.0, for the actual materials used in Greece (at least in view of the authors), it was decided that the best approach would be the use of materials that already exist in the software database and are characterised by similar basic properties to the ones commonly used in Greece. Indeed, the mortar and the extruded polystyrene used for the simulations had very similar basic properties with the corresponding materials used in Greece. Unfortunately, this is not the case for the masonry. In Greece, the vast majority of the bricks used in outer wall constructions are horizontally perforated with a big percentage of voids of large dimensions. The study of simultaneous heat and moisture transfer inside such materials is very complex, since there are many additional phenomena taking place, related to the shape and size of the voids, the relationship between the properties of the ceramic material of the brick's solid matrix and the properties of air inside the voids, etc. Consequently, a reliable estimation of heat and moisture transfer parameters of those perforated bricks would be very difficult. Furthermore, there is not a perforated brick in the material database of the software used. Under the circumstances, the authors decided to use the solid brick masonry, the properties of which are fully recorded in the WUFI's database. The encouraging fact is that the thermal conductivity coefficient and the water vapor diffusion resistance factor are very close to the ones given for the perforated brick masonry by the Greek regulation for the building elements' insulation (Papadopoulos 1998). An additional observation that led to the choice of an already existing (in the database) brick is that, even with the use of EN1745, the approach of the thermal properties of the bricks commonly used in Greece would be approximate. The basic properties of the materials used are summarized in Table 1.

Table 1. Properties of the materials used in the wall constructions examined.

Material	Bulk Density	Porosity	Heat Capacity	Heat conductivity (dry)	Water Vapor Diffusion Resistance Factor
	kg/m^3	m^3/ m^3	J/kgK	W/mK	-
lime cement Plaster	1900	0.24	850	0.8	19
XPS(extruded polystyrene)	40	0.95	1500	0.03	100
Solid Brick Masonry	1900	0.24	850	0.6	10

3.2 *Outdoor and indoor climate*

As was mentioned before, the analysis of building components' hygrothermal performance requires input data for the indoor and the outdoor climate. In this study, the weather data for the region of Thessaloniki were generated with the use of METEONORM 5.0. The file with the hourly weather data was used as input for WUFI pro-4.0. Since Thessaloniki is not included in the cities recorded in the program's catalogues, the weather data were generated with the help of approximations made by the program, based on information for the site (longitude, latitude, etc.). A simple way to check the accuracy of the weather file generated was to compare the mean monthly values for air temperature and relative humidity derived by the software and those values as they are given by Hellenic National Meteorological Service (H.N.M.S.). This comparison is illustrated in Table 2. It is obvious that the weather data generated with the use of METEONORM are reliable.

The indoor climate file was manually created by the authors. It was assumed that the indoor air temperature and relative humidity was steady for each month. The criterion for the decision on whether the indoor climate was controlled for a certain month, was the relationship between this month's outdoor climatic parameters' values and the values of temperature and relative humidity that ensure the thermal comfort in a building. Analytically, if the outdoor air relative humidity was between 35% and 70%, and the outdoor air temperature was between 22ºC and 26ºC in summer or 18ºC and 22ºC in winter, the indoor air temperature and relative humidity was assumed to be equal to the mean monthly values given by H.N.M.S.. Otherwise, the indoor climate was assumed to be controlled and the fixed values for the parameters of temperature and humidity were 20ºC and 55% for winter and 24ºC and 55% for summer correspondingly. This procedure of setting the values of indoor climatic parameters based on the outdoor climate is summarized in Table 3.

Table 2. Comparison of climatic data generated with the use of METEONORM and of those given by H.N.M.S. for the region of Thessaloniki.

Month	Air temperature (mean monthly values)		Air relative humidity (mean monthly values)	
	(ºC)		(%)	
	H.N.M.S.*	ME-TEONORM	H.N.M.S.	ME-TEONORM
January	5,0	5,0	75,8	74,6
February	6,6	6,7	73	71,8
March	9,7	9,6	72,9	71,5
April	14,2	14,2	68,5	68
May	19,4	19,5	64,3	63,7
June	24,2	24,2	56,3	56,6
July	26,5	26,5	53,6	53,1
August	25,9	25,8	55,4	54,9
September	21.7	21,8	62,5	62,4
October	16,1	16,1	70,4	68,5
November	11,0	10,9	77,3	76,5
December	6,8	6,7	77,8	76,3

Table 3. Indoor climatic data determination.

Month	Air temperature (mean monthly values)		Air relative humidity (%) (mean monthly values)	
	(ºC)		(%)	
	H.N.M.S.	Indoor Conditions	H.N.M.S.	Indoor Conditions
January	5,0	20	75,8	55
February	6,6	20	73	55
March	9,7	20	72,9	55
April	14,2	20	68,5	55
May	19,4	19,4	64,3	64,3
June	24,2	24,2	56,3	56,3
July	26,5	24	53,6	55
August	25,9	25,9	55,4	55,4
September	21.7	21,7	62,5	62,5
October	16,1	20	70,4	55
November	11,0	20	77,3	55
December	6,8	20	77,8	55

4 RESULTS AND DISCUSSION

4.1 *Introductive discussion*

The hygrothermal performance of the four outer wall construction types that were presented above was analyzed with the use of WUFI pro-4.0. The four walls were examined for the four basic orientations. The duration of the analysis was two years. The reference year that was generated with the use of METEONORM was used to simulate the outdoor climate. The reason that the duration of the analysis was two years, although there is one reference climatic year that is repeated, is that the materials in the components are characterized by a certain initial moisture content. Therefore, the first year of the analysis is not considered to be representative of the components' performance, since it involves the drying of the materials and the establishment of a balance between the component and its surroundings. It is the whole of the results for the second year of analysis that represents the typical performance of the component.

The time step of the analysis was one hour. This is a time step that would not normally lead the iterative procedure for the numerical solution of the set of the two coupled partial differential equations to convergence failures.

The following discussion of the results is conducted in two sections. In the first section, comparisons among the results of the analysis, relatively of course to the moisture in construction, for the same structures of different orientations are made. In the second section, the comparisons are made among different wall structures of the same orientation. The discussion is focused on the hygric performance of the components, since water is a major factor influencing the degradation mechanisms of building materials.

4.2 *Comparisons of the same wall constructions for different orientations*

The four different constructions were studied separately. For the wall construction of Case A, it is the component facing the West that deals with the most severe problems related to moisture in construction. Indeed, the western components' layers that are exposed to natural conditions are the ones that suffer the most from moisture accumulation and fluctuations.

The lime cement plaster on the external face of the wall is the most exposed layer of the component. It is in the western orientation that the water content in this layer reaches very often high values. Furthermore, the fluctuations of water content in this layer are bigger when the western orientation is considered. Besides, it is the outer lime cement plaster of the western component that suffers often from very high values of relative humidity, not only at the position near the external surface, but also near the interface with the solid brick masonry.

The picture is the same for the solid brick masonry. The masonry belonging to the western component reaches higher maximum and minimum values of water content during the typical year. Furthermore the duration of the periods with high water content in the masonry is bigger for the components facing the West. The masonry of the western component suffers more than the ones belonging to components of other orientations from fluctuations of the water content.

At the interface between masonry and plaster on the internal face of the wall, there is not any significant difference among the orientations. This is also the case for the plaster on the internal face of the wall. This is expected, since as one proceeds towards the internal face of the component, the influences of the climate (and, consequently, of the orientation) are decreasing.

For the cases B-D the results agree with the previous ones, concerning Case A, in the fact that the worst orientation for outer wall constructions in Thessaloniki is the western. This becomes obvious in the values and fluctuations of water content and relative humidity of the most exposed layers of each construction. Due to the limited available space, the results for each layer of each wall construction are not discussed analytically, as was the case for Case A.

The fact that the critical, from the point of view of hygric performance, orientation for every type of wall construction is the western finds its explanation in the analysis of the region's climate. The weather data used as input for WUFI pro-4.0, when analyzed, give the diagram of Figure 2 for the driving rain sum. From this diagram, it is obvious that the western components are subjected to much more wetting due to driving rain in comparison to the components of the other orientations. This fact explains the results that were presented above.

4.3 *Comparisons of different structures of the same orientation*

The orientations that were studied were the eastern and the western ones. The first was chosen to be studied because the corresponding values of driving rain and solar radiation are not extreme, and the second because it is characterized by big driving rain loads. Since the tendencies observed were similar, the other orientations were not studied (no serious differentiations could come up). The results that are discussed stand for all the orientations. The different constructions will be in this paragraph referred to as Case A, B, C, D (Fig. 1).

The exterior lime cement plaster is severely exposed to the outdoor climate for all the constructions. Nevertheless, it is in Case B that the water content in this layer reaches the highest values and that the fluctuations of these values are the largest. It should be pointed out that the differences among the hygric performances of the exterior plasters belonging to the various Cases are not significant.

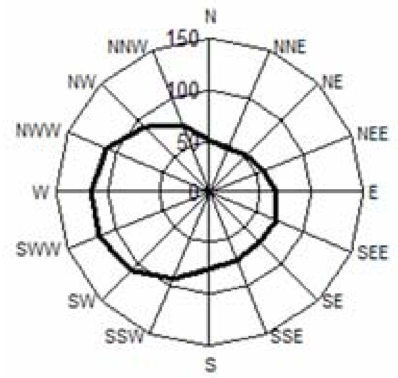

Figure 2. Driving rain sum for different orientations (climate of Thessaloniki).

The interior lime cement plaster is clearly more protected in the Cases where insulation is used. The differences among those cases are minor. The maximum values of water content in the interior lime cement plaster appear (with very small differences from the other cases) in Case C.

The solid brick masonry of Case B is the one presenting the lowest water content. The solid brick masonry that seems to face the most serious problems (when of course moisture issues are considered) is the external masonry of Case D. Writing the Cases in order, starting with the one with the most protected masonry, one would write: Case B, Case D (internal masonry), Case A, Case C, Case D (external masonry).

In what concerns the layer of insulation, the one suffering from higher water contents is the one of Case B. This is expected since in this Case, the layer of insulation is severely exposed to the outdoor climate.

In the final stage of the results' review, an estimation of the condensation risk (in winter) in every construction was made. The positions more prone to condensation were specified for each type of construction. The risk of water vapor condensation for these parts of the construction was evaluated.

For the wall construction of Case A, the position prone to vapor condensation is inside the masonry, around 5cm from the outer masonry surface. At the beginning of the analysis, the high initial moisture content leads to high levels of relative humidity. However, since the results of the second year of analysis are discussed, this fact is not taken into account. During the second year of analysis (a typical one for the component's performance), there are extended periods of high relative humidity (around 70%). Although there is not any condensation occuring at this position, the periods of rather high relative humidity are extended.

For the wall construction of Case B, the position prone to vapor condensation is near the interface between the insulation layer and the outer cement plaster layer. The review of the results show that very high values of relative humidity (reaching sometimes 100%) are often reached instantly at this position. However, this fact is attributed to wetting due to driving rain and not to vapor condensation. This approach is enhanced by the fact that this occurrence of high values of relative humidity is more frequent in the western components (orientation with the heaviest driving rain loads).

For the wall construction of Case C, the position prone to vapor condensation is near the interface between the insulation layer and the solid brick masonry layer. The review of the results show that high values of relative humidity (around 80%) are often reached at this position. This fact shows a tendency for condensation at this position.

For the wall construction of Case D, the position prone to vapor condensation is near the interface between the insulation layer and the outer solid brick masonry layer. The results are similar to those of Case C.

5 REFERENCES

Fagerlund, G. 1996. Moisture mechanics as a tool for service life prediction. In C. Sjöström (editor), *Durability of building materials and components*; *Proc.of seventh intern. conf. on Durability of Building Materials and Components, Stockholm, 19-23 May 1996*. London : E & FN Spon.

Geving, S., Karagiozis, A. & Salonvaara, M. 1997. Measurements and two-dimensional computer simulations of the hygrothermal performance of a wood frame wall, *Journal of Thermal Insulation and Building Envelopes* 20:301–319.

Hagentoft, C.E. & Blomberg T. 2000. *1D-HAM, coupled heat, air and moisture transport in multilayered wall structures. Manual with brief theory and an example, version 2.0. 2000.*

Künzel, H.M. 1994. *Verfahren zur ein- und zweidimensionalen Berechnung des gekoppelten Wärme- und Feuchtetransports in Bauteilen mit einfachen Kennwerten.* Dissertation Universität Stuttgart.

Lea, F.M. & Hewlett, P.C. 1998. *Lea's chemistry of cement and concrete.* London: Arnold.

Neville, A.M. 1995. *Properties of concrete.* harlow, Essex : Addison Wesley Longman Limited.

Papadopoulos, M. 1998. *Buildings' insulation* (in Greek) . Thessaloniki: Kyriakidis.

Rendell, F., Jauberthie, R. & Grantham, M. 2002. *Deteriorated concrete: inspection and physicochemical analysis*. London: Thomas Telford.

Comparison of two structural reuse options of two-by-four salvaged lumbers

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ABSTRACT: Two wood frame single detached houses were carefully deconstructed by hand and almost 650 pieces of salvaged lumbers were tested for their visual grades, structural defects and physical characteristics. In comparison with the normally conducted dismantling process twice as much time was needed to deconstruct the wood frame houses carefully by hand. 10 percents of the salvaged lumbers showed lower visual grade than their original ones. The strength value of the salvaged lumbers, originally SPF grade 2, was 18.8MPa where the design strength for SPF Grade 2 was 21.6MPa. Lumbers having modulus of elasticity of 9.6GPa or higher showed a strength value of 21.4MPa. In contrast, a MOE controlled selecting procedure led to a decreased in the yield ratio to 70%. The new reuse option compared to the reuse option applied now showed a 1.5 times larger contribution to carbon storage and only half of the CO2 emission.

1 INTRODUCTION

Demand for recycle changes reflecting the social and economical situations. Considering the change in demand for recycle processes it is important to investigate different types of recycling methods and to determine the best recycling method in accordance with societal and environmental aspects.

Wood is known to be a material that can be recycled. And there are two cycles for this resource circulation as shown in figure 1. One is the resource circulation created by reforestation (circulation A) and the other one is the resource circulation created by recycle of the materials (circulation B). Both resource circulations work as to store carbon in the wooden materials.

Wooden products can store carbon in themselves. And as long as we use them wooden products release no CO2 to the atmosphere. In terms of men operated resource circulation reuse is an effective way to store carbon and leads to less CO2 emission. Almost 50 years ago salvaged lumbers were commonly reused as structural materials such as posts and beams for single detached houses in Japan. But recently wooden waste is mainly recycled as chip boards and fuel resources.

Lumbers composing the wood frame constructions are standardized dimension lumbers. And these dimension lumbers seem to have high potential to be reused as structural elements. Falk et al. (1999 and 2000) have done a series of tests to evaluate the strength properties of dimension lumbers salvaged from four buildings deconstructed at U.S. Army’s Fort Ord. And Chini et al. (2001) have investigated the mechanical properties of salvaged lumbers.

If we can predict the strength properties of the salvaged lumbers using visual grading or machine grading we may be able to use them as structural elements again. And if we can take a little more care and spent more time in deconstructing we can produce higher quality salvaged lumbers from the deconstruction site. The purpose of this study is to compare two different

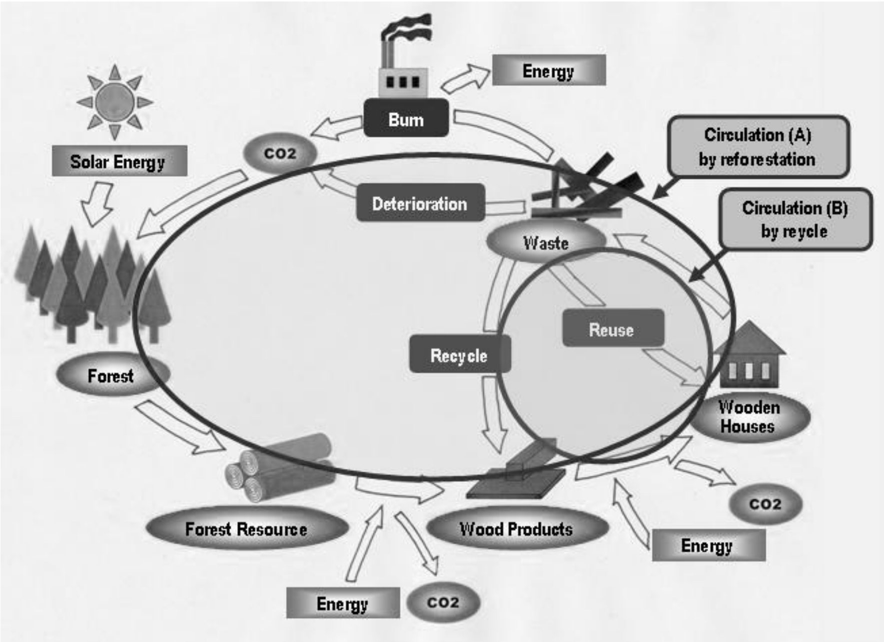

Figure 1. Resource circulation of wooden materials.

reuse options for two-by-four salvaged lumbers and to investigate two different types of grading to maximize this reuse.

2 DECONSTRUCTION

2.1 *Summary of the deconstructed houses*

Two wooden frame single detached houses were deconstructed carefully by hand. Specific data of the two houses are given in table 1 and shown in figure 2. House A was constructed in 1988 and deconstructed in 2004 and house B was constructed in 1986 and deconstructed in 2005. The service life of house A was 16 years and that of house B was 19 years. The service lives of both houses were extremely short compared to the average service life of the wooden houses in Japan that is approximately 35 years.

Table 1. Summary of the deconstructed houses.

	House A	House B
Number of stories	2	2
Total floor area (m^2)	94	143
Year of construction	1988	1986
Year of construction	2004	2005

2.2 *Summary of the deconstruction process*

It took 13 days to deconstruct house A and 25 days to deconstruct house B. As it usually takes 10 days to dismantle a 150m^2 wood frame house by machine the careful deconstruction process took more than twice as many days than the normally conducted machine dismantling. The labor spent in both deconstruction works are summarized in figure 2. Almost 60% of the deconstruction works were spent in the process of deconstructing the structural lumbers and sheathing panels and removing the nails from the lumbers. This result indicates that we have to spend more time to deconstruct the structural elements to obtain a larger fraction of less damaged salvaged lumbers.

Figure 2. The two deconstructed house. Left is house A and right is house B.

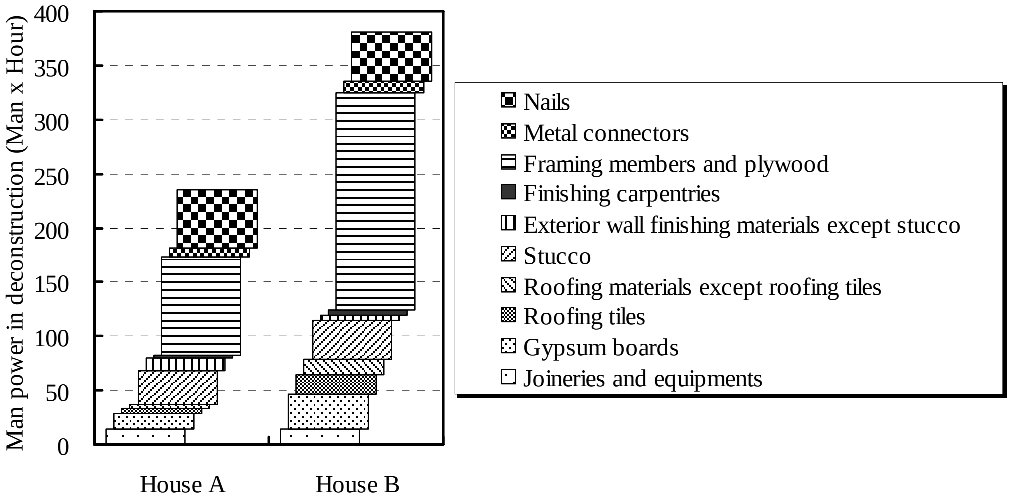

Figure 3. Labor spent in removing components and materials from the deconstructed houses.

The cost spent in hiring the workers for careful deconsruction is calculated to be approximately 8000JPY/m^2 and the cost spent in hiring the workers to dismantle in the usual way is calculated to be approximately 4000JPY/m^2. Twice as much labor cost is neccsssary to carefully deconstruct the wood frame houses.

3 GRADING AND TESTING METHODOLOGIES

3.1 *Test specimens*

633 pieces of 2 by 4 lumbers were selected from the salvaged lumbers of the two deconstructed houses. The cross section size of the test specimens was 38mm by 89mm and the length was 2340mm. The original visual grade of the test specimens was S-P-F grade No.2 and this was identified by the stamps of the lumbers. The total volume of the lumbers tested was one-third of the total volume of the salvaged lumbers.

3.2 *Visual grading*

All the test specimens were visually graded following the visual grading rules stipulated in the Japanese Agricultural Standard for the wood frame structural lumbers. And the esthetic appearance of the test specimens was also inspected according to the in-house standard of a home builder. The visual inspection was conducted by professional visual graders.

3.3 *Inspection of the nail holes*

Most of the nail holes on the lumbers are due to the construction and deconstruction works. As nail hole does not appear on the surface of the virgin lumbers they are not regarded as defects in the visual grading rules of the Japanese Agricultural Standard. To confirm the effect of the nail holes on the strength properties of the reclaimed lumbers the amount of the nail holes were measured for the side-surfaces and the end-surfaces of the lumbers.

3.4 *Machine grading*

The moduli of elasticity of all the test specimens were measured using a grading machine.

3.5 *Bending test*

All the test specimens were tested for their bending properties. A four point loading bending test was conducted. The support span was 1602mm that was 18 times of the depth of the test specimens. And the distance of the two loading points was 534mm that was one-third of the support span. The modulus of elasticity and the bending strength of each test specimen were derived from the bending test.

4 RESULTS AND DISCCUSSION

4.1 *Results of the visual grading*

The grade distribution of the visually graded lumbers is shown in figure 4. Almost 90% of the lumbers satisfied their original grade. This means almost 90% of the lumbers had no damage stipulated in the Japanese Agricultural Standard (JAS) grading rules even after experiencing the construction and deconstruction process. Approximately 5% of the lumbers were degraded as No.3 or Utility and approximately 5% of them could not meet the criteria of the lowest structural grade. The types of the defects of the lumbers that had lower grades than their original ones are shown in figure 5. These defects such as stain, end check, wane, processing damage, hole and decay are produced during construction, use and deconstruction of the houses. As the lumbers were very carefully taken from the deconstructed houses the grade distribution was as shown in figure 4 and this is supposed to be the best possible yield.

Approximately 20% of the lumbers did not satisfy the esthetic criteria stipulated in the in-house standard of a home builder. As almost all of the esthetically dissatisfied lumbers were included in the No.2 grade lumbers the yield ratio of the lumbers that satisfied both the visual grade for No.2 and the esthetic criteria was measured to be approximately 70%.

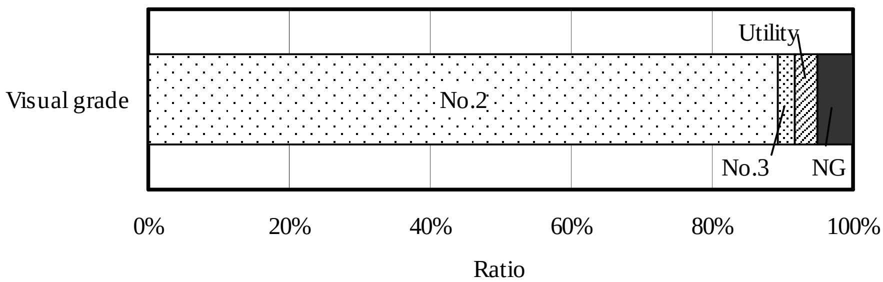

Figure 4. Grade distribution. The ratio is based on lumber pieces.

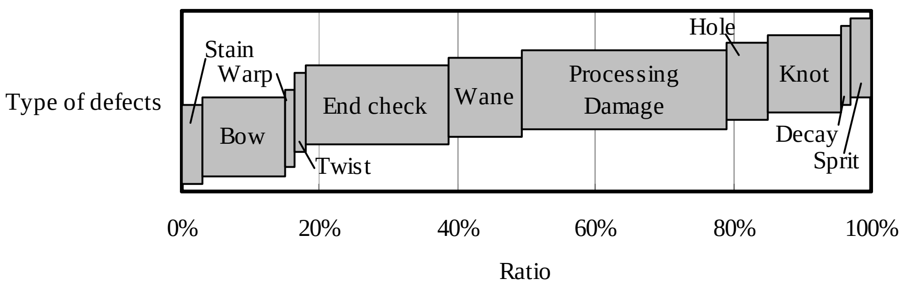

Figure 5. Grade reducing defects. The ratio is based on lumber pieces.

4.2 *Bending properties of the lumbers*

The distribution of modulus of elasticity (MOE) and modulus of rapture (MOR) are shown in figure 6 and 7. The distribution of MOE and MOR of the whole test specimens and that of the test specimens graded as JAS grade S-P-F No.2 are both shown in these figures. The average MOE was measured as 11.0GPa for both non-graded and graded lumbers. And the average MOR was measured as 48.6MPa for the non-graded lumbers and 49.2MPa for the graded lumbers.

The strength value of the test specimens of each cell was calculated by the following formula:

$$\textit{Strength value} = (\textit{5\% lower tolerance limit of } MOR_{0.05}) \times (\textit{Safety factor}) \quad (1)$$

where *Safety factor = 1.5*
$MOR_{0.05} = 5^{th}$ *percentile of bending strength*

The strength value of the lumbers graded as JAS grade S-P-F No.2 was calculated as 18.8MPa where the design strength for the same grade is given as 21.6MPa in the Japanese National Building Code. The salvaged lumbers showed 13% lower strength values.

4.3 *Effect of the nail holes on the flexural properties*

The effect of the number of nail holes in various surfaces of the lumbers on their MOE and MOR values is shown in figure 8 & 9. An observable decrease of MOE and MOR values occurred when the total amount of nail holes on the two narrow surfaces of the lumbers was

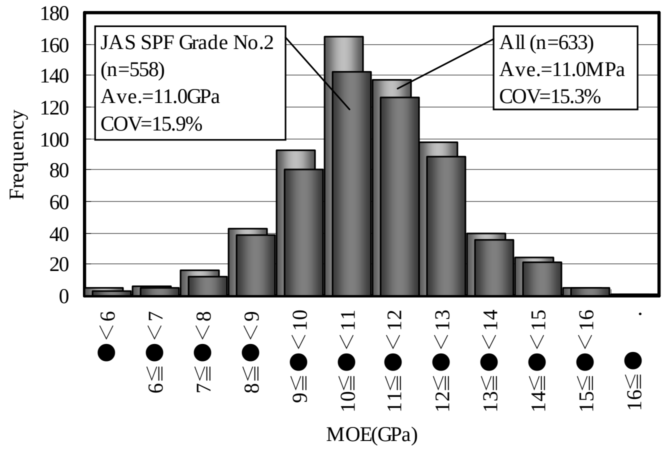

Figure 6. Distribution of MOE.

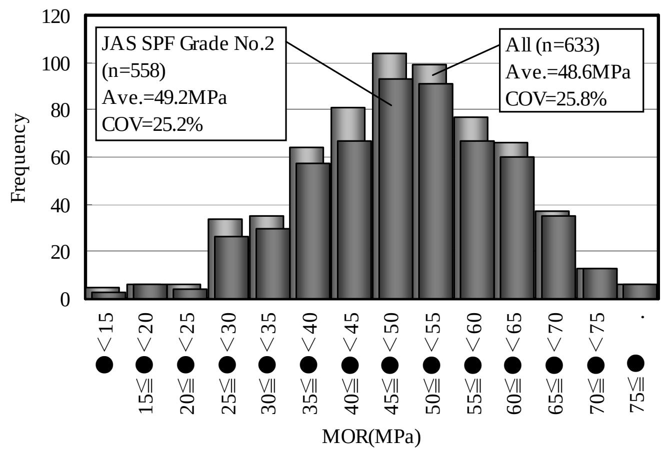

Figure 7. Distribution of MOR.

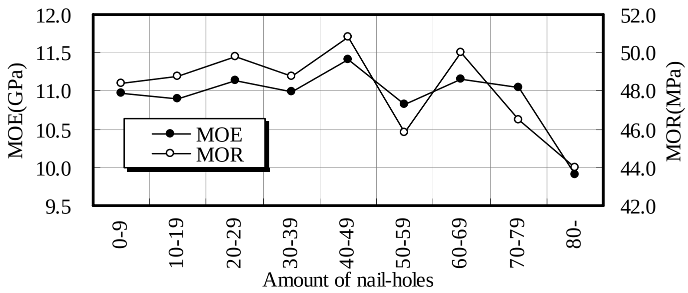

Figure 8. Effect of the narrow surface nail-holes on the flexural properties of the lumbers

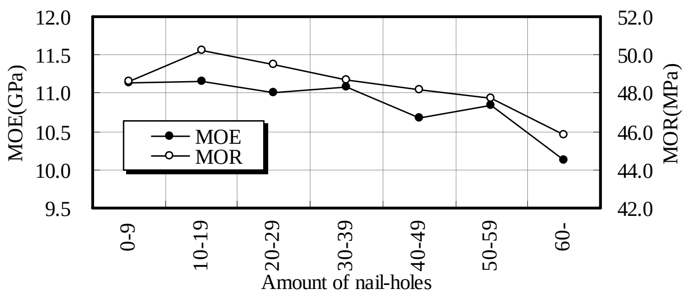

Figure 9. Effect of the broad surface nail-holes on the flexural properties of the lumbers

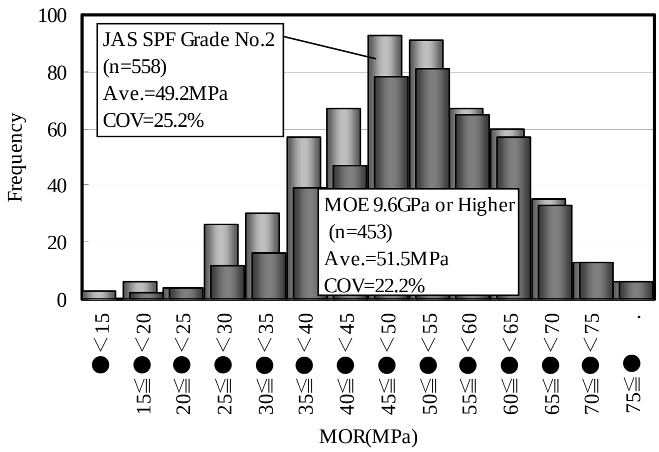

Figure 10. Distribution of MOR of the machine graded lumbers.

more than 70. A reduction in these values was also observed when the total amount of nail holes on the two broad surfaces of the lumbers was more than 50.

The lumbers were selected for reuse according to the number of nail holes on their surfaces. Lumbers that had 70 or less nail holes on their narrow surfaces and 50 or less nail holes on their broad surfaces were selected. The yield ratio for that selection was 72%. And the strength value for that cell was calculated as 19.1MPa and this value was still lower than the design value given in the Building Code.

4.4 *Flexural properties of the machine graded lumbers*

In this case the lumbers were selected according to the MOE values measured by the grading machine. Test specimens that had 9.6GPa or higher MOE were selected. The distribution of the MOR for this cell is shown in figure 10. The strength value for this cell was calculated as 21.4MPa and this was almost equivalent to the design value given in the Building Code.

The yield ratio was 72% and this was the same as for the selection based on the allowable number of nail holes. The MOE based selection seems to work better in choosing lumbers with higher bending strength.

5 ENVIRONMENTAL ADVANTAGES OF REUSING LUMBER

The carbon balance was calculated for the two scenarios summarized in table 2. Scenario 1 is the reuse scenario and scenario 2 is the recycle scenario.

Table 2. Scenarios

	Scenario 1: Reuse scenario	Scenario 2: Recycle scenario
Building	A wood frame construction of 100m^2 floor area.	A wood frame construction of 100m^2 floor area.
Deconstruction /Dismantle	Deconstructed by hand and takes 20 days to deconstruct. Three workers work on site everyday.	Dismantled by machine and takes 10days to dismantle. Three workers work on site everyday.
Transportation of the workers	Distance from home to deconstruction site is 30km. Automobiles are used for transportation and every worker drives their own car.	Distance from home to dismantle site is 30km. Automobiles are used for transportation and every worker drives their own car.
Wooden materials from the deconstruction site	Total volume: 10m^3 Lumbers 2000mm or longer:7m^3 Lumbers shorter than 2000mm: 3m^3	Total volume: 10m^3 Wood waste:8m^3 Mixed waste: 2m^3
Reuse /Recycle methods	Lumbers 2000mm or longer: - 50% reused. Yield ratio of the raw material is 90%. - 50% recycled as particleboard. Yield ratio of the raw material is 100% and 10% of the products are lost in the trimming process. Lumbers shorter than 2000mm: - 100% recycled as particleboard. Yield ratio of the raw material is 100% and 10% of the products are lost in the trimming process.	Wood waste: - 100% recycled as particleboard. Yield ratio of the raw material is 80% and 10% of the products are lost in the trimming process. Mixed waste: - 100% transported to the landfill site.
Transportation	Reuse process: - Lumbers are transported to the precut mill from the deconstruction site by trucks (loading capacity 2tons). The distance between the deconstruction site and the precut mill is 50km. Recycle process: - Lumbers are transported to the woodchip plant from the deconstruction site by trucks (loading capacity 4tons). The distance between the deconstruction site and the woodchip plant is 50km. - Woodchips are transported to the particleboard mill from the woodchip plant by trucks (loading capacity 10tons). The distance between the woodchip plant and the particleboard mill is 100km. Mixed waste: - Mixed waste is transported to the recycle plant from the deconstruction site by trucks (loading capacity 4tons). Then the mixed waste is transported to the landfill site by trucks (loading capacity 10tons). The distance between the construction site and the recycle plant is 50km and the distance between the recycle plant and the landfill site is 100km.	

The total CO2 emission for the two scenarios was calculated using the CO2 emission data collected by Nakajima et al. (1996) and Kodama et al. (2004). The results of the calculations are shown in figure 11. The CO2 emission for the reuse scenario (scenario 1) was calculated as 940kg-C/100m^2 where that for the recycle scenario (scenario 2) was calculated as 1652kg-

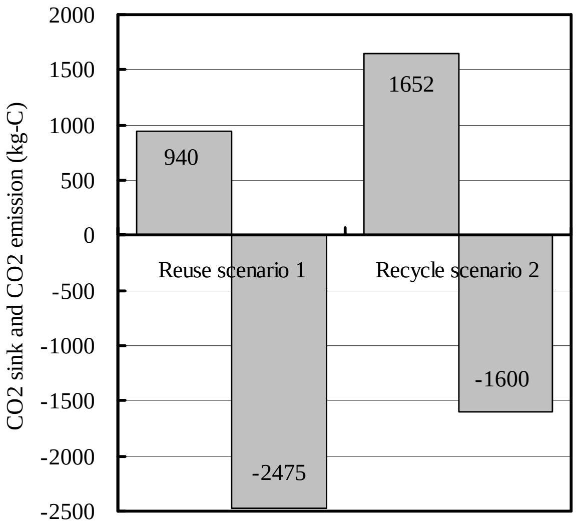

Figure 11. Carbon balance calculated for the reuse scenario and the recycle scenario.
Legend: Left is the result of the reuse scenario 1 and right is the result of the recycle scenario 2.

C/100m^2. And the sink of carbon for the reuse scenario was calculated as 2475kg-C/100m^2 where that for the recycle scenario was calculated as 1600kg-C/100m^2. We can expect a net carbon sink of approximately 1500kg-C/100m^2 when we carefully deconstruct and reuse most of the lumbers of the two single semi detached houses investigated. In case of dismantling a 100m^2 single detached houses, when the wood is recycled as particleboard and the mixed waste part goes to landfill, the net carbon balance will be approximately 0.

6 CONCLUSIONS

In comparison with the normally conducted dismantling process twice as much time was needed to deconstruction the wooden frame houses carefully by hand and to salvage less damaged lumbers. The machine grading selection can give higher strength value to the salvaged lumbers but the yield ratio will be reduced by the selecting procedure. Compared to the normally processed recycling process 1.5 times much carbon sink and almost half CO2 emission can be expected by reusing the lumbers. This result indicate that reusing salvaged lumbers is one of the effective way for reducing the CO2 emission. But on the other hand it is not economically acceptable to remove lumbers piece by piece from houses being deconstructed. If we can give some economic advantages to these salvaged lumbers they will become competitive with the virgin lumbers.

REFERENCES

Falk, RH et al. 1999. Effect of damage on the grade yield of recycled lumber. *Forest Products Journal*. Vol.49. No.7/8: 71-79.

Falk, RH et al. 2001. Engineering evaluation of 55-year-old timber column recycled from an industrial military building. *Forest Products Journal*. Vol.50. No.4: 71-76.

Chini, RA et al. 2001. Grading and mechanical properties of salvaged lumber. *Proceedings of the CIB Task Group 39 - Deconstruction Meeting*. Wellington. New Zealand. 2001: 138-162.

Nakajima, S et al. 1996. Energy consumption and environmental impact due to producing wood based materials. *Proceedings of CIB W70 Helsinki '96 Symposium*. Helsinki. Finland. 1996:185-188.

Kodama, Y et al. 2004. Development of technologies to promote deconstruction and recycle of wooden houses - Development of material flow calculation method. *Report of the Building Research Institute*. No.140: 43-46.

Building deconstruction and building heritage preservation: a case study at Porto's world heritage historical centre

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ABSTRACT: The feasibility of the application of building deconstruction practices to historical buildings is addressed here, by determining its contribution to preserve both tangible and non-tangible heritage, and to the reduction of non-renewable resources consumption. Therefore, a case studies of a building's rehabilitation at the historical center of Porto, Portugal, is here presented and analyzed. The flows of materials' mass and embodied energy related to the rehabilitation process were accounted, analyzed, and compared, as a way to measure the environmental benefits of materials reuse, and the preservation of their historical value. The results showed that in general selected dismantling highly contributes to the reduction of waste, as well to reduce the loss of the embodied energy, especially when compared with scenarios of only façade retention. The preservation of historic value of construction systems and materials also benefits of such approach by supporting an open-design methodology, in order to select and update design solutions and construction procedures during the rehabilitation process.

1 INTRODUCTION

Buildings keep changing over time as a consequence of a set of driving forces that Brand (1994) identified as technology, money and fashion. Users interact with their living space dynamically by changing, adapting and extending it until it is possible to fulfill the established requirements as well as possible.

Over time, redundancy, deterioration and obsolescence processes are the causes for the degradation and, at the end, for the demolition of a building.

Preserving the historic character of buildings has the double challenge of preserve the memory of a whole body (e.g. typology, construction systems, materials) and fulfill a new set of requirements to avoid redundancy and obsolescence to occur.

However, adequately matching both the functional aspects and the available typologies may be a solution in order to solve redundancy problems and to help in the preservation of the major part of a building, taking into account the deterioration and obsolescence levels. Maximal preservation of tangible and non-tangible heritage as a whole becomes possible if the redevelopment procedures are taken into account for the existing structures, components and materials.

Open design procedures maximize information trade of between the design team and the site workers based on a building deconstruction approach. Options for the use of technologies and materials could than be made, but must also be supported by the analysis of the existent constraints and the different possibilities of preservation, according to their fitness to the new requirements.

To maximize the preservation of a building is also to maximize the reuse of materials, to minimize waste flow and resources consumption, and to extend the lifetime of a building as a whole. Dealing with building heritage preservation integrates the aspects of building's life cycle management.

2 BUILDING PRESERVATION

2.1 *Heritage and building preservation*

Different degrees of building's rehabilitation can be addressed, from the retention of all parts of an existing building to the retention of all or a single part of the building's envelope. More drastic options of redevelopment are related to the category of façade retention and involve the construction of a new building behind the existing façade (Highfield, 1991). Less drastic procedures are related, for example, to restoration works.

Although the conceptual advantages or disadvantages of each level of rehabilitation, such as construction costs, construction time, materials flows, durability, lifetime extension, codes compliance, energy efficiency, and maintenance costs, aspects of redundancy, deterioration, and obsolescence should be taken in account for a decision making.

Redundancy is related with the over-supply of certain type of buildings, or with their low flexibility to be easily reused. Redundancy is, for example, the cause why a building stays empty for a long time period. Due to redundancy, spatial and economic values are usually valuated regarding other aspects, such as the building entity and the memory of the traditional construction systems and techniques.

Deterioration is mainly related with time and is caused by climatic influences and users activities. Deterioration also determines the maintenance tasks over time.

Obsolescence is more complex and less physical in a certain way. Obsolescence may be defined as the process of an asset going out of use and determines the moment for an adaptation or a demolition. In this sense, obsolescence is a measure of a building's usefulness over time (Douglas, 2002) or an indicator of the degree of usefulness of a building in relation with a set of requirements or constraints: economic, functional, physical, social, legal restraints, and aesthetic.

These three aspects determine the availability of buildings for rehabilitation or demolition, and also the needed level of redevelopment. For example, in historic centres, a lot of buildings become empty due to their redundancy, and an option for façade retention is a minor price to pay compared to the preservation of the historic townscape.

New functional, fashion and comfort requirements don't match normally with historic buildings, leading to a partial demolition, usually its core, or to façade retention, in order to achieve a more flexible object for the rehabilitation process.

From the demolition processes, an outflow of construction debris and an inflow of new materials take place in the building. In most of the times, if maintenance tasks have been done, these materials and components had not reached their end of life.

The embracement of the four dimensions of sustainable construction as stated by Bourdeau (1999), can contribute to a solution for the redundancy problem by integration of use and available typology, leads to: economic, functional, environmental and social. This approach may help to minimize environmental impacts of building materials by reuse of existing structures, reduce materials use and reuse building components (Kibert, 2005), and, at some extent, to avoid the loss of non-tangible heritage, such as crafts works of ancient construction processes and the historical value of some materials.

2.2 *Deconstruction and preservation*

In order to maximize the building reuse, deconstruction techniques should be applied to the rehabilitation works.

Sequentially removing of the different elements of the building is useful to:

- Dismantle the unwanted components and materials without damage to other useful elements;
- Dismantle the elements that could not be repaired onsite;
- Analyze the critical parts, such as structural elements, without damaging the components and materials that can be reused.

Although, in comparison with traditional demolition, deconstruction procedures show some disadvantages, such as more costs, more time, and the need of more human labor (Macozoma, 2001), but it is an effective way to salvage the historic value of craftsman's work and ancient materials.

Additional costs with deconstruction may be minimized with the low costs of rehabilitation procedures in comparison with the construction of a new building, according to Highfield (1991) and Douglas (2002).

In order to integrate information obtained from deconstruction, changes in traditional closed design methodologies are necessary. An open design strategy enables the management of the sequential information obtained from deconstruction processes, regarding the deterioration of the construction systems, components, and materials. In this approach, design of construction's details to be improved and replaced can be better and more accurate, and also leads to a more flexible design trough feedback between design team and contractor.

3 CASE STUDY

3.1 *Building's characterization*

The building is located at the historical centre of the city of Porto, at the North of Portugal. In 1996, UNESCO declared the historical centre of Porto as World Cultural Heritage. The street of Caldeireiros, where the building is located, is one of the most ancient streets in the historic centre, and over the 19th century a new set of buildings replaced the ancient structures, creating a new urban plot type. Its extensive length, in proportion with its width, characterizes this urban plot (Fig. 1,2 and 3). The plot is south/north oriented.

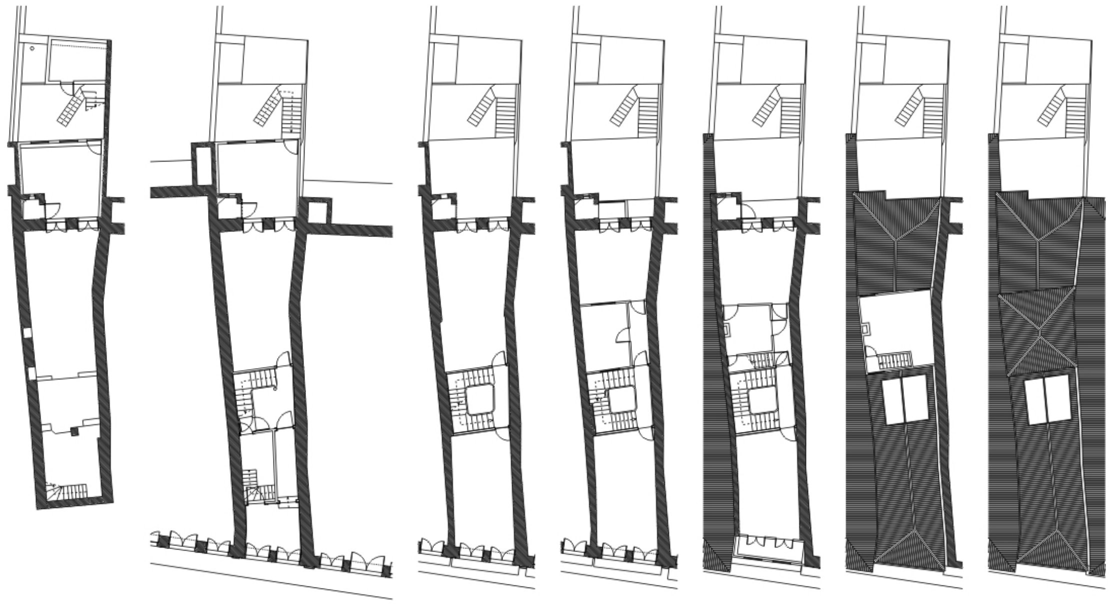

Figure 1. Existing building: plans.

The spatial configuration of this building typology is organized around a central staircase with rooms turned to the street and rooms turned to the backyard. Later, the ground floor and the basement of this residential building were used as a printing office. Because of functional transformations along the years, some processes of addition occurred: first, a central small floor was added as an expansion of the residential area, and later the ground floor and the basement were extended to the backyard. Although these transformations occurred, the building core (e.g. typology, building system, materials) remained intact.

The original structural system was characterized by structural stonewalls that support the wooden structure of floors and roofs. The interior walls were built with wood. Also the pavements, stairs, and external and interior windows and doors frames were made from wood. Ceramic tiles covered the entire roof. The upper addition was built with a wooden structure and the backyard additions, more recent, were built with concrete and ceramic bricks.

Some building pathologies were detected during the building analysis, damaged because water infiltrations trough the roofs. Some beams of the roofs were partially damage because of water infiltrations on the joining surface of the tiles with the stonewalls. Some beams of the third floor were also damaged due to a small fire. The windows and doors frames in the south façade were very damaged as a consequence of climatic agencies, such as sunlight, rain and wind. The windows and doors frames in the north façade were quite well preserved.

3.2 *The project and the renewal process*

The building was part of an urban renewal action coordinated by FDZHP, a foundation created by the City in order to manage new projects in the historic center, and that was responsible for the monetary funds to support the building's rehabilitation. A religious association for social support owned the building and it was their intention to create a communitarian building for youth education. For this purpose the owner indicated the organizational program: a bar, a library, 4 education rooms, 2 office rooms and a meeting room. The architects Rogério Amoêda and Cristina Pinheiro developed the renewal project.

After having analyzed the building typology, taking in account the intentions of the owner, it was possible to conclude that it was rather easy to match them, solving the problem of redundancy too (Figs. 2,3,4, and 5). This is seen as an opportunity to achieve the following goals:

1. To preserve the traditional typology and traditional construction systems and materials as part of the building's tangible and non-tangible heritage;
2. To reduce the environmental impacts of building materials.

Analyzed the building typology, made it possible to conclude that it was rather easy to match the internal spatial structure with the new functional program, solving the problem of redundancy (Fig. 2 and 3). However, it was needed to get information about the level of conservation of the construction systems, such as structure, pavements, walls, ceilings and roofs.

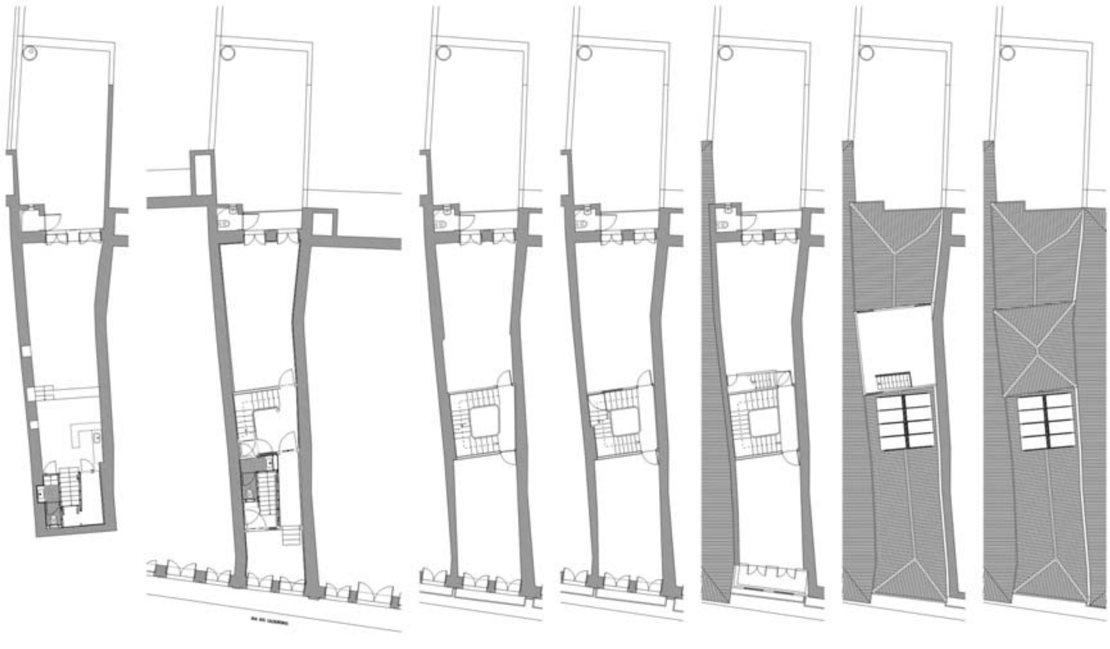

Figure 2. Renewal project: plans.

The methodology applied was based on a deconstruction approach: step-by-step, the unwanted or damaged parts were removed without damaging other elements, and inspection actions were made to the critical elements, such as the wooden structures of the floors and roofs. These procedures made possible to get a detailed overview of the building's conservation state, given a feedback to the design team in order to adjust the technological solutions to be applied. A combination of partial demolition (Figs. 4 and 5), maintenance, and repair actions was necessary in order to improve the reused parts, such as floors and roofs' structure (Fig. 5 and 6), wood pavements, windows and doors frames, ceramic tiles, plaster ceilings and gypsum mortars. New light materials were added according to the existent construction systems, such as wooden pavements, and light gypsum cardboard walls and ceilings.

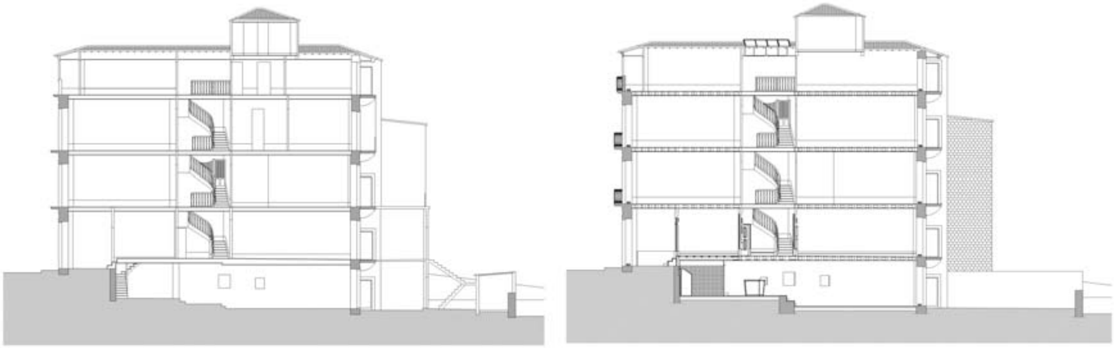

Figure 3. Longitudinal sections: (a) existing building, (b) renewal.

Figure 4. North and South façades: (a) before and (b) after renewal.

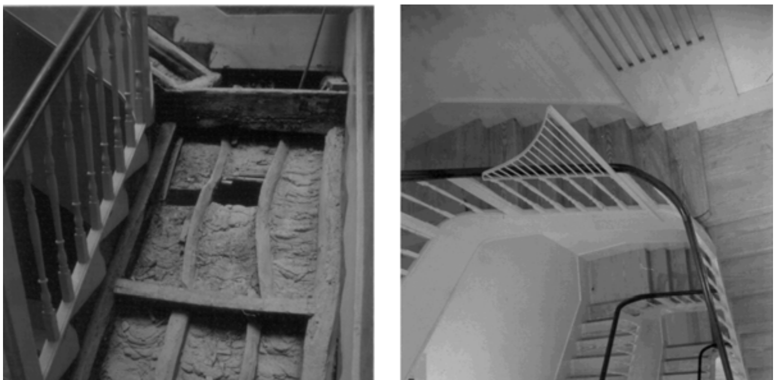

Figure 5. Staircase: (a) during deconstruction process and (b) after renewal.

Figure 6. Interior of the wooden roof: (a) during deconstruction process and (b) after renewal.

3.3 *Results and discussion*

The renewed building keeps the historic value of the existent typological and construction characteristics by successfully preserving the construction systems and materials, accomplishing the first goal of the design team that was to preserve the tangible and non-tangible heritage.

In order to verify the second goal's achievement, it was performed an analysis of the flows of the building materials and embodied energy by accounting the weight for the existing building, for the deconstruction waste, for the reuse materials, for the new materials input, and for the renewed building (Table 1).

The result of this analysis shows that the initial and final values for the global weight are just slightly different, increasing from 1,570,454 kg to 1,587,881 kg. This small increase is due to the great amount of the reuse materials, and to the lightweight of the new materials added. The high mass and dimension of the building's envelope and its conservation imply a large amount of reused materials. In a scenario of only façade retention, also considered, this value is comparable as can be seen in Table 2. The result related to embodied energy shows a reduction of the initial value of 1,773,085 MJ to 1,587,881 MJ. This result is justified by the high embodied energy of the waste, that includes materials such as concrete, ceramic bricks, carpet, and linoleum.

Four specific indicators are defined, total embodied mass/m^2 = TEM/CA, total embodied energy/m^2 = TEE/CA, embodied mass of materials reused/m^2 = EMMR/CA, and embodied energy of materials reused/m^2 = EEMR/CA. Furthermore two relative indicators are defined and expressed in %: embodied mass of materials reused divided by the total embodied x 100% = (EMMR/TEM) x 100%, and embodied energy of materials reused divided by the total embodied energy x 100% = (EEMR/TEE) x 100%. This set of indicators is shown in table 2. The same construction area for the renewal and the scenario of façade retention was considered, although there is no project design for this last option.

The indicators show an increase of the value of the embodied mass per square meter from 5621 kg/m^2 to 6137 kg/m^2 due to the reduction of the construction area after the rehabilitation of the building. The value of the embodied energy per square meter also shows an increase from 6346 MJ/m^2 to 6535MJ/m^2.

Comparison between the renewal and the scenario of façade retention was performed just for the reuse of materials and waste produced for each case. Due to the weight of the building's envelope the mass reuse per square meter decreases from 5004 kg/m^2 to 4385 kg/m^2, and the embodied energy per square meter decreases from 5004 MJ/m^2 to 4385 MJ/m^2. Although these differences may be not significant, the indicators related to waste show significant differences between waste per square meter that increase from 367 kg/m^2 to 605 kg/m^2, and between embodied energy per square meter that increases from 1849 MJ/m^2 to 2468 MJ/m^2.

However the results don't show great differences between the analyzed items due to the great weight of the building's envelope, the results for the rehabilitation are not far from the initial condition of the building, and are better in comparison with the scenario of façade retention. It should be argued that for this scenario, a concrete structure is the most common solution to avoid high costs with steel frame structures or wooden structures, and so this structural option will highly increase the weight of the building and its embodied energy. Regardless the costs, an option for the steel frame structure would also raise highly the value for embodied energy.

Table 1. Analysis of materials' flows and Embodied Energy.

Materials		Existing		Waste		Reused		New Input		Renewed	
	EE coefficient MJ/kg	Weight kg	EE M J	Weight kg	EE M J	Weight kg	EE M J	Weight kg	EE M J	Weight kg	EE M J
Brick	3.0**	1881	5643	1881	5643	0	0	0	0	0	0
Carpet	72,4*	23	1665	23	1665	0	0	0	0	0	0
Cement mortar	2.0*	26,375	52,750	24.042	48,084	2333	4666	33,220	66,440	35,553	71,106
Concrete	1,3*	23,640	30,732	23,640	30,732	0	0	1968	2558	1968	2558
Glass	15,9*	4175	66,383	2600	41,340	1575	25,403	2575	40,943	4150	65,985
Glazed tiles (ancient)	8.0**	403	3224	0	0	403	3224	0	0	403	3224
Glazed tiles (modern)	8.0**	225	1800	225	1800	0	0	208	1664	208	1664
Gravel	0.1*	0	0	0	0	0	0	42,858	4286	42,858	4286
Gypsum board	6.1*	0	0	0	0	0	0	1539	9388	1539	9388
Lime mortar	1.0**	41,626	41,626	14,353	14,353	27,273	27,273	0	0	27,273	27,273
Linoleum	116.0*	34	3944	34	3944	0	0	0	0	0	0
Paint	88.5*	1480	130,980	1480	130,980	0	0	1296	114,696	1296	114,696
Plaster	4.5*	5850	26,325	4177	18,797	1673	7529	0	0	3034	13,653
Plywood	10.4*	0	0	0	0	0	0	636	6614	636	6614
Roof tiles	3.0**	4067	12,201	4067	12,201	0	0	4067	12,201	4067	12,201
Sand	0.1*	0	0	0	0	0	0	3744	374	3744	374
Steel (structural)	35.0*	166	5810	166	5810	0	0	1243	43,505	1243	43,505
Stone	0.8*	3456	2730	0	0	3456	2730	10,395	8212	13,851	10,942
Stone (structural)	0.8*	1,412,208	1,115,644	0	0	1,412,208	1,115,644	0	0	1,412,208	1,115,644
Varnish	88.5*	115	10,178	115	10,178	0	0	147	13,010	147	13,010
Wood (hard, rough)	2.0*	20,160	40,320	1524	3048	18,636	37,272	816	1632	19,452	38,904
Wood (soft, shingle)	9.0*	24,570	221,130	16,638	149,742	7932	71,388	6198	55,782	14,130	127,710
XPS (insulation)	72.0**	0	0	0	0	0	0	121	8712	121	8712
,Total		1,570,454	1,773,085	94,965	478,316	1,475,489	1,294,769	111,031	390,017	1,587,8811	1,690,910

* (CBPR, 2007)
** (Berg, 1992)

Table 2. Comparative analysis.

Indicator	Unit	Existing	Renewed	Option 2*
Construction Area (CA)	m^2	279	259	259
Embodied Mass (EM)	kg	1,570,454	1,587,881	-
EM/CA	kg/m^2	5621	6137	-
Embodied Energy (EE)	MJ	1,773,085	1,690,910	-
EE/CA	MJ/m^2	6346	6535	-
Materials Reuse (MR)	kg	-	1,475,489	1,413,906
Embodied Energy of MR (EMR)	MJ	-	1,294,769	1,134,410
MR/CA	kg/m^2	-	5703	5465
EMR/CA	MJ/m^2	-	5004	4385
Deconstruction Waste (DW)	kg	-	94,965	156,548
Embodied Energy of DW (EDW)	MJ	-	478,316	638,675
DW/CA	kg/m^2	-	367	605
EDW/CA	MJ/m^2	-	1849	2468
MR/EM	%	-	93	-
EMR/EE	%	-	77	-

* Option 2: only façade retention.

4 CONCLUSIONS

Historic buildings' preservation is related to a set of constraints such as urban policies, developers' practices, real estate market, and design principles. However, the procedures to preserve historic buildings are ruled by the concepts of redundancy, deterioration, and obsolescence. These concepts determine the degree of the building's rehabilitation

By adequate matching of both typology and use, redundancy problems can be solved. This gives an opportunity to address the technical aspects of preserving both tangible and non-tangible heritages, as shown in the case study. Maximal reuse of a building by preserving its core is an effective way to extend its life considerably, both at systems and material levels.

Application of deconstruction procedures, in an open design context, allows analyzing components and materials deterioration, in order to establish repair procedures and specific technologic solutions.

In comparison with scenarios of façade retention, as shown in the results obtained for the case study, preserving the existing as a whole reduce significantly the embodied mass and the embodied energy, and reduce the amount of construction debris.

Although, not being the goal of this study, future work can be extend to a set of buildings representing different degrees of rehabilitation and include a detailed cost analysis for the construction and maintenance phases.

REFERENCES

Berg, B. 1992. *Ecology of Building Materials*. Oxford: Architectural Press.

Bordeau, L. 1999. *Agenda 21 in Sustainable Construction*. Rotterdam: International Council for Research and Innovation in Building and Construction.

Brandt, S. 1994. *How Buildings Learn*. New York: Penguin Books.

CBPR. 2007. *Embodied Energy Coefficients*. Centre for building Performance Research, Victoria University of Wellington, New Zealand. http://www.vuw.ac/cbpr/documents/pdfs/ee-coefficients.pdf.

Douglas, J. 2002. *Building Adaptation*. Oxford: Butterworth-Heinemann.

Highfield, D. 1991. *The Construction of New Buildings Behind Historic Facades*. London: Chapman and Hall.

Kibert, C.J. 2005. *Sustainable Construction*. New Jersey: John Wiley & Sons.

Macozoma, D. 2001. *Building Deconstruction*. Rotterdam: International Council for Research and Innovation in Building and Construction.

Organisation of reverse logistics tasks in the construction industry

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ABSTRACT: The construction industry is characterized by a high material intensity and hence by a large amount and a heterogeneous mix of construction and demolition waste (C&D waste). The high and diversified amount of C&D waste is not only a today's challenge with respect to recovery of components and materials but also with respect to the organisation of the associated logistic activities.
The purpose of this paper is to sensitize for the difficulties of the design of efficient logistic processes in construction due to the characteristics of construction waste streams. Therefore, the concept of reverse logistics - which has already attracted intensive research in manufacturing industry - is applied to the construction industry particularly focusing on deconstruction projects. It is shown that the main structural difference between the construction industry and the manufacturing industry, regarding take-back of products, i.e. waste, does not refer to waste treatment or recovery processes, but to the organisation of the collection and the design of logistic processes from the building site to the recovery facilities.

1 INTRODUCTION

The research field of reverse logistics has attracted intensive research efforts during the last years. Its application covers a wide variety of products from different industries. Thereby, reverse logistics can, among others, defined in the following way: reverse logistics encompasses the logistics activities all the way from used products no longer required by the user to products again usable in the market. It is the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin, for the purpose of recapturing value or proper disposal (Stock 1998, Jayaraman et al. 2003).

Comprehensive overviews on reverse logistics can be found, for instance, in Dekker et al. (2004) and Dyckhoff et al. (2004). Case studies, and other industry related work, concentrate, for instance, on the organisation of reverse logistic tasks in the automotive industry (e.g. Schultmann et al. 2006), in the industry for electrical and electronic equipment (e.g. Walter & Spengler 2005), or the publishing industry (e.g. Wu & Cheng 2006). Other research addresses issues of the organisation of reverse logistics in the context of closed-loop supply chains and reverse supply chain management (cf. Kovacs et al. 2006, Srivastava & Srivastava 2006, Jayaraman 2006, Krumwiede 2002, Tibben-Lembke 2002, Ferguson & Browne 2001, Pochampally & Gupta 2005, Boulton 2005) and the organisation of logistics networks (Fleischmann et al. 2000, Jayaraman et al. 2003). However, some papers also provide overviews on literature and conducted case studies in the field of reverse logistics, which are only briefly referred to in this paper. These papers comprise, for instance, Fleischmann et al. (1997) giving on overview on quantitative models for reverse logistics, Fleischmann et al. (2000) highlighting conducted case studies, and Dowlatshahi (2005), who is developing a framework for effective design and implementation of remanufacturing/recycling operations in reverse logistics after analysing various case studies. A more recent literature review on green supply-chain management and, hence, also on reverse logistics can be found in Srivastava (2007).

The construction industry, however, has not yet attracted much research concerning the organisation of reverse logistic tasks. The return or take-back of construction and demolition waste (C&D waste) at the end-of-life of a building or during repair and renovation processes has not been subject to reverse logistic concepts.

Hence, the objective of the paper is to highlight challenges for the application of reverse logistics in construction, especially focusing on deconstruction projects. Therefore the remainder of the paper is organized as follows: At first, an overview on the concept of product return and of reverse logistics as applied in the manufacturing industry is given. Based on this overview, conclusions for the applicability of this concept to the construction industry are drawn. Therefore, waste streams of the construction industry are briefly discussed and resulting challenges for the organisation of the operational logistic tasks, i.e. the collection of C&D waste at the site as well as its transportation to recovery facilities or disposal sites are revealed.

2 PRODUCT RETURN AND REVERSE LOGISTICS

The stages of reverse logistics can be distinguished into

1. collection,
2. inspection/selecting/sorting processes,
3. reprocessing,
4. and redistribution.

All of the activities require a certain amount of operational logistic activities, i.e. transport of products or waste (cf. Dekker et al. 2004). Hereby, Fleischmann et al. (2000) state that product recovery not only reverses the product stream with the consequence that there are many supply sources (collection points, e.g. retailers) and few demand points (recovery facilities, disposal sites), but that the design is complicated by the high uncertainty in many factors.

Discussing reverse logistics, the following aspects need to be taken into consideration (Dekker et al. 2004):

1. motivation of enterprises to take action in reverse logistics as well as reasons for product return,
2. processes carried out in logistics with the aim of recovering value,
3. characterisation of returned products, and
4. actors executing the reverse logistics activities.

2.1 *Motivation for reverse logistics, reasons for product return and recovery processes*

The *motivation* for the involvement of companies into reverse logistic activities is differentiated into profit-oriented, legislative as well as corporate citizenship drivers (Dekker et al. 2004, Schultmann et al. 2006).

The profit-oriented drivers comprise direct as well as indirect benefits. While direct benefits can be achieved from returned products used as substitute for new input materials (for instance metal scrap for steel) as well as by cost reductions for disposal and new raw materials procurement. Indirect benefits are expected from the established “green image” of the enterprise, improved customer and supplier relations as well as the anticipation of legislation. Especially the indirect benefits refer to the movement of sustainable development and the increasing awareness of different stakeholders, for instance, the government, the common public, non-governmental institutions as well as interest groups to act environmentally friendly. Among others, typical tasks are to preserve natural resources, to reduce green house gas emissions, and to prevent global warming. This holds true especially for the legislation for end-of-life products and wastes and social acceptance of the enterprise in the public.

Despite the profit-oriented drivers, legislative acts might force companies to take action in reverse logistics. This also comprises extended producer responsibility (EPR) where producers, in their role as manufacturer of goods, are legally obliged to take back and recycle goods. Examples in Europe are regulations for electrical and electronic equipment WEEE (European Parliament 2003) as well as the manufacturers' responsibility for the take back of batteries and cars.

In addition to profit-oriented and legislative drivers, an enterprise is also dependent on the "license to operate" issued by its stakeholders. This especially refers to the expectation of the companies environment that enterprises behave social as well as environmental conscious. Disregarding this issue might result in unfavourable influences on companies' business operations by its environment, i.e. its stakeholders.

However, not just the take back of end-of-life products is subject to economic, legislative and social drivers. Reverse logistics in general comprises the reverse flow of goods from the end consumer back to the manufacturer, i.e. including processes after take back of products. This might happen because of several reasons. Generally, three return stages of products can be differentiated: manufacturing returns, distribution returns, and customer returns. Manufacturing returns comprise returns because of a material surplus, returns from quality controls or production leftovers or by-products. Distribution returns might be product recalls, business-to-business (B2B) commercial returns (e.g. unsold products, damaged delivery), and functional returns, such as distribution items or packaging. In comparison, customer returns are, e.g., reimbursement guarantees, i.e. business-to-consumer commercial returns, warranty or service returns (maintenance and repair), or end-of-use (e.g. returnable bottles or leased cars) and end-of-life returns (Dekker et al. 2004). The latter may also apply to C&D waste.

After return, the value in these products or waste can be recovered by various actions. Recovery actions are, for instance, reuse or resale, repair, refurbishing, recycling or incineration. For an overview as well as complete definitions of recovery actions for used products and waste it is referred to (Thierry et al. 1995, Dekker et al. 2004).

2.2 *Characterisation of returned products*

Performing reverse logistic activities depends on the characteristics of the returned product. These include the following (Dekker et al. 2004):

1. composition,
2. deterioration, and
3. use pattern.

The product *composition* describes factors like the presence of hazardous materials, the material heterogeneity of the product and the size of the product. The size of the product has significant impact on the transport and handling of the product, e.g. choice of appropriate mode of transportation as well as means of transport. *Deterioration* of a product considers the intrinsic deterioration of a product, i.e. aging during its use, the homogeneity of deterioration, i.e. if all parts age equally, and the economic deterioration, which addresses the decline of the value of the product, for instance, outdated products like old computer technology. The *use pattern* of a product is especially relevant for the collection phase of the product. It comprises issues like the location, i.e. different locations and effort for collection (individual or institutional use, collection point or individual take back), intensity and duration of use.

2.3 *Actors and responsible parties in reverse logistic activities*

A distinction of actors in reverse logistics activities can be made between (e.g. Dekker et al. 2004, Fuller & Allen 1995):

- forward supply chain actors,
- specialised reverse chain actors, and
- opportunistic actors.

In particular, responsible parties can be, among others: original equipment manufacturer (OEM), wholesalers or retailers, independent intermediaries, specialised recovery enterprises, third party reverse logistics service providers, and governmental institutions, like municipalities taking care of waste collection.

3 REVERSE LOGISTICS IN CONSTRUCTION

Applying reverse logistics concepts from the manufacturing in the construction industry, one faces numerous difficulties. These difficulties mainly arise from the more complex nature of the forward supply chain as depicted in Figure 1.

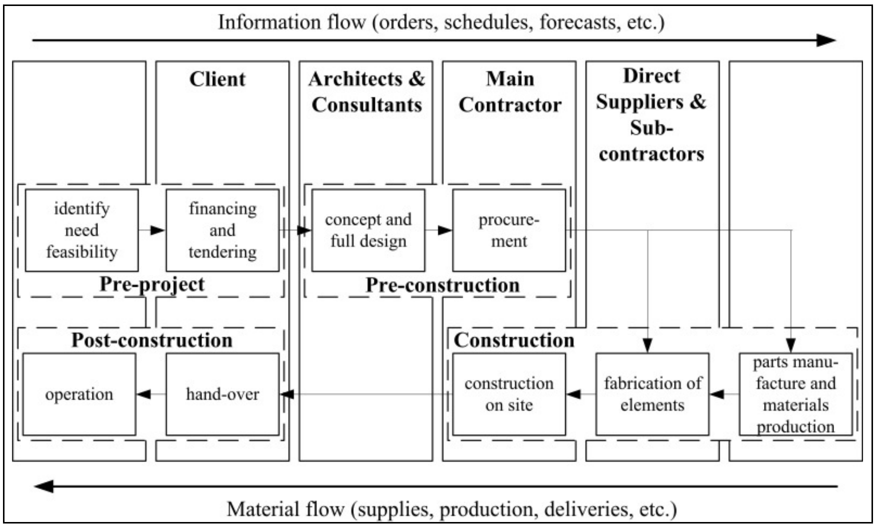

Figure 1. Forward construction supply chain (Lowe & Leiringer 2006).

In comparison to the products of the manufacturing industry, such as electrical and electronic equipment, the "products" of the construction industry, i.e. civil objects, like houses, bridges or roads, have a long life cycles and are immobile. Due to their size and immobility the recovery of civil objects usually takes place on-site (Dekker et al. 2004). Concluding, reverse logistics operations in the so called reverse supply-chain are more difficult due to the higher number of actors (contractor, supplier, sub-supplier) and materials of different composition, degree of deterioration, and use pattern. An example of different recovery options for C&D waste is depicted in Figure 2.

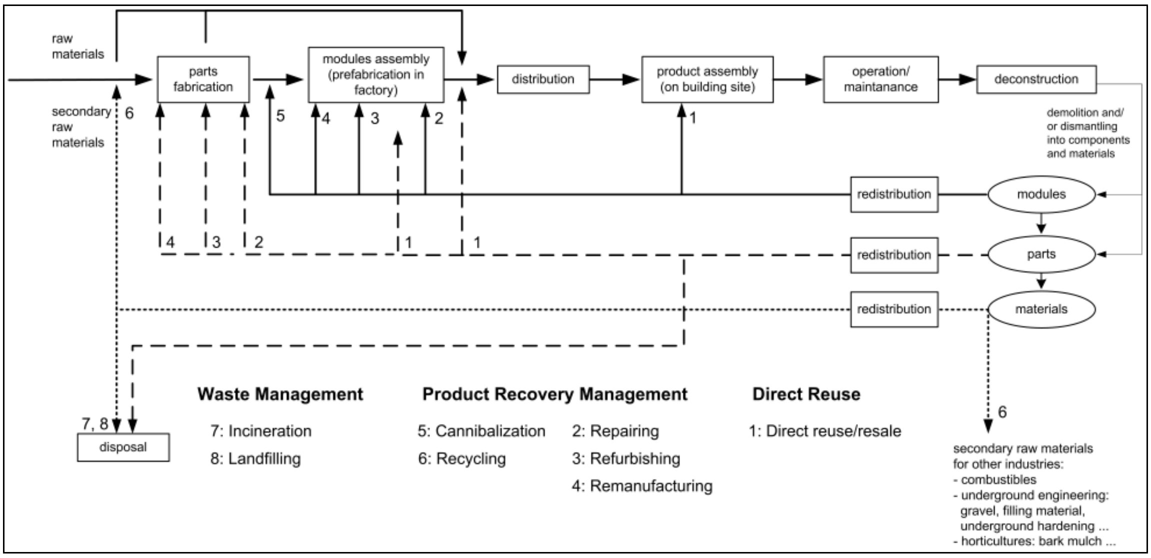

Figure 2. Recovery options for C&D waste (Schultmann & Sunke 2006).

3.1 *Motivation*

The motivation for construction companies to participate in reverse logistics is likely the same as in the manufacturing industry. Regarding profit–orientation a reduction of costs for disposal by selective deconstruction and separation of C&D waste can be realized. Additional gains are expected from the resale or recovery of valuable components and materials, for instance deconstructed aluminum framed windows, steel bars, wood, or bricks.

Legislative pressure is put on the enterprises by construction specific legislation. This legislation comprises regulations for the handling of C&D waste. In Europe, this is mainly laid down in the European Council Directive 91/156/EEC (revised Framework Directive on Waste, amending Council Directive 75/442 EEC) and Council Directive 91/689 EEC on Hazardous Waste, amended by national legislation as the Recycling and Waste Management Act (Kreislaufwirtschafts- und Abfallgesetz: KrW-/AbfG) in Germany.

While the first two drivers for reverse logistic tasks focus on economic and legal aspects, the third factor addresses social consideration. It focuses on the fact that an enterprise depends on the "license to operate" issued by the people and institutions in its living environment (cf. section 2). Due to environmental concerns, also construction enterprises face pressure to act according to the principle of sustainability, i.e. waste avoidance and reuse in order to foster resource preservation and emission avoidance. The "green image" gained by environmentally friendly business operations can help to win the favor of the public.

3.2 *Characterisation of material and waste flows in the construction industry*

When construction materials are classified, it has to be differentiated between constituent parts and components of buildings used for construction and construction waste. According to Kibert, five general component categories of houses can be distinguished (Kibert et al. 2000):

1. manufactured, site-installed commodity products, systems, and components with little or no site processing (e. g. boilers, valves, electrical transformers, doors, windows, lighting, bricks),
2. engineered, off-site fabricated, site-assembled components (e. g. structural steel, precast concrete elements, glulam beams, engineered wood products, wood or metal trusses),
3. off-site processed, site-finished products (cast-in-place concrete, asphalt, aggregates, soil),
4. manufactured, site-processed products (dimensional lumber, drywall, plywood, electrical wiring, insulation, metal and plastic piping, ductwork),
5. manufactured, site-installed, low mass products (paints, sealers, varnishes, glues, mastics).

At the end of the life-cycle of a building, these components represent potentially recoverable materials and parts which are transformed into waste.

Apart from deconstruction this waste also arises during the erection of buildings. These materials can be classified according to the European Waste Catalogue (EWC) (European Comission 2002). The EWC contains a number of different waste descriptions, e. g. for wastes from inorganic chemical processes, waste from the photographic industry as well construction and demolition wastes (including excavated soil from contaminated sites), as exemplarily depicted in Table 1.

Depending on the actors involved in reverse logistics processes in construction, as addressed in the next section, different networks of collection points (supply sources) and recovery facilities or disposal sites (demand points) for C&D waste exist. If third party service providers are authorized with the pick up and recovery or disposal C&D waste, from the viewpoint of this service providers, numerous collection points (construction sites) exist and difficult transport problems, i.e. vehicle routing problems, occur. If the construction operator itself is responsible for the collection and transport of C&D waste to the recovery facility or disposal site against some charge, easy network structures and planning problems occur. However, this situation only occurs for very small deconstruction projects usually processed by small construction enterprises, usually engaged in regional business and contracts with private persons.

Table 1. C&D wastes according to the EWC (European Comission 2002).

EWC Code	Description
17 01	**concrete, bricks, tiles and ceramics**
17 01 01	concrete
17 01 02	bricks
17 01 03	tiles and ceramics
17 01 06	mixtures of, or separate fractions of concrete, bricks, tiles and ceramics containing dangerous substances
17 01 07	mixtures of, or separate fractions of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06
17 02	**woods, glass and plastic**
17 02 01	wood
17 02 01	glass
17 02 03	plastic
17 02 04	glass, plastic and wood containing or contaminated with dangerous substances
17 03	**bituminous mixtures, coal tar and tarred products**
17 03 01	bituminous mixtures containing coal tar
17 03 02	bituminous mixtures other than those mentioned in 17 03 01
17 03 03	coal tar and tarred products
17 04	**metals (including their alloys)**
17 04 01	copper, bronze, brass
17 04 02	aluminum
17 04 03	lead
17 04 04	zinc
17 04 05	iron and steel
17 04 06	tin
17 04 07	mixed metals
…	…

3.3 *Actors and responsibilities for C&D waste management*

The responsibility for C&D waste management in deconstruction projects is usually assigned to the general contractor, i.e. the construction enterprise or the responsible sub-contractor.

The contractor or sub-contractor has to organize the disposal of waste. Thereby, C&D waste can be sorted on-site and collected in transportable devices, for instance, containers. The aim of the contractor is to reduce disposal costs. This is usually realized by selective deconstruction and high degree of C&D waste separation. After deconstruction and sorting, either the contractor delivers the waste to recovery facilities or disposal sites against a fee or directly contracts with a specialised reverse chain actor, e.g. a recycling company, who picks up the containers of C&D waste on site for money and resells, recovers or disposes the C&D waste itself.

4 CHALLENGES IN THE ORGANISATION OF REVERSE LOGISTIC PROCESSES FOR CONSTRUCTION

Concentrating on the analysis of reverse logistics concerning C&D waste, recovery strategies for C&D waste have already been discussed intensively in literature. This comprises, for instance, research on deconstruction and recovery techniques (e.g. Tam & Tam 2006, Kuo 2006, Thormark 2000) and the use of various building materials and components after recovery (e.g. Rao et al. 2007). Therefore, in the following, the focus is shifted to the organisation of operational logistic tasks, i.e. the collection of C&D waste at the deconstruction site and its transport to recovery facilities or disposal sites. Hereby, the statement of Fleischmanns et al. (2000) (cf. section 2) especially holds true for construction, where common problems occurring are to be found in transportation activities, i.e. inefficient route planning and empty truck loads, so called deadheads.

These problems result from the characteristics of the construction industry, which differs from the manufacturing industry in many points. Among them are the complex and heterogeneous structure of the product, the long life time of the product and its immobility, the uncertain and non static waste accumulation in deconstruction projects, as well as the varying locations of construction sites, i.e. varying collection points but only a few recovery facilities and disposal sites as addressed before. Considering these particularities less space of freedom is given in the development of logistic strategies.

In the following, we therefore particularly focus on the influence of the characteristics of the construction industry on:

– actors and responsibilities,
– means of transport, and
– modes of transport.

C&D waste management in deconstruction projects is usually undertaken by the general contractor, i.e. the construction enterprise or the responsible sub-contractor. Accordingly, the contractor or sub-contractor is responsible for the disposal of the waste, as discussed before. This waste can be sorted on-site and collected in, for instance, containers. Either the contractor delivers the waste to recovery facilities or disposal sites for a fee or directly contracts with a specialised reverse chain actor, e.g. a recycling company. This actor picks up the containers or trucks loaded with C&D waste on site and resells, recovers or disposes the C&D waste itself.

Especially for reverse chain actors, the efficient transport of C&D waste is difficult. In contrast to the manufacturing, the location of the deconstruction sites is varying and usually the only accessible way is road transport mode. Hence, trucks with special equipment (for instance, special hangers to safely store deconstructed windows for resale) or container trucks are used. Thereby, also the composition of C&D waste hampers efficient reverse logistic activities. The size and quality of C&D waste is usually not standardised and the waste often contains unexpected hazardous substances. Deadheads cannot be avoided due to the missing planning certainty with respect to the forecast of the amount, place and time of the pick up of goods or collection from the construction sites and usually different role of the actor (a recycling plant usually does not deliver a deconstruction site with recovered components or recycled material). Instead, pick up tours have to be calculated every time an order is made by a contractor and complicated vehicle routing problems occur every time a new order arrives.

5 CONCLUSIONS

The aim of this contribution was to investigate the challenges of the application of reverse logistics to the construction industry. Special focus was put on deconstruction projects and C&D waste. It could be shown that reverse logistic activities also become important in construction, especially with respect to the need of the recovery of C&D waste trying to establish closed loop material loops.

It can be concluded, that the main structural difference between the construction industry and the manufacturing industry regarding take back of products, i.e. waste, does not refer to waste treatment or recovery processes, but to the organisation of the collection and the design of logistic processes from the building site to the recovery facilities due to the special characteristics of the construction industry and its products.

Accordingly, future research has to focus on the logistic processes from the source of origin of C&D waste to the first step down the process chain, i.e. the connection between construction sites or collection points and recycling or recovery facilities.

6 REFERENCES

Boulton, L. 2005. Reverse Logistics: Closing the Supply Chain Loop. *Supply Chain Practice* 7(1): 4-13.

Dekker, R., Fleischmann, M., Inderfurth, K. & van Wassenhove, L.N. 2004. *Reverse Logistics – Quantitative Models for Closed-Loop Supply Chains*. Berlin-Heidelberg-New York: Springer.

Dowlatshahi, S. 2005. A strategic framework for the design and implementation of remanufacturing operations in reverse logistics. *International Journal of Production Research* 43(16): 3455–3480.

Dyckhoff, H., Lackes, R. & Reese, J. (eds) 2004. *Supply Chain Management and Reverse Logistics*. Berlin-Heidelberg-New York: Springer.

European Comission 2002. *Consolidated European Waste Catalogue (EWC).* https://www.europa.eu.int/eur-lex/en/consleg/pdf/2000/en_2000D0532_do_001.pdf, retrieved 21 March 2006.

European Parliament 2003. *Directive 2002/96/EC of the European Parliament and of the council of 27 January 2003 on waste electrical and electronic equipment (WEEE).*

Ferguson, N. & Browne, J. 2001. Issues in end-of-life product recovery and reverse logistics. *Production Planning and Control* 12(5): 534-547.

Fleischmann, M., Bloemhof-Ruwaard, J.M., Dekker, R., van der Laan, E., van Nunen, J. & van Wassenhove, L.N. 1997. Quantitative models for reverse logistics: A review. *European Journal of Operational Research* 103: 1-17.

Fleischmann, M., Krikke, H.R., Dekker, R. & Flapper, S.D.P. 2000. A classification of logistics networks for product recovery. *Omega* 28(6): 653–666.

Fuller, D.A. & Allen, J. 1995: A typology of reverse channel systems for post-consumer recyclables. In J. Polonsky & A.T. Minut-Winsatt (eds), *Environmental Marketing: Strategies, Practice, Theory, and Research*: 241-266. Binghamton, NY: Haword Press.

Jayaraman, V., Patterson, R.A. & Rolland, E. 2003. The design of reverse distribution networks: Models and solution procedures. *European Journal of Operational Research* 150: 128–149.

Jayaraman, V. 2006. Production planning for closed-loop supply chains with product recovery and reuse: an analytical approach. *International Journal of Production Research* 44(4): 981-998.

Kibert, C., Sendzimir, J. & Guy, G. B. 2000. Construction ecology and metabolism: natural system analogues for a sustainable built environment. *Construction Management and Economics* 18: 903-916.

Kovacs, G., Spens, K.M. & Korkeila, R. 2006. Stakeholder response to future chances in the reverse supply chain. *International Journal of Logistics Systems and Management* 2(2): 160-176.

Krumwiede, D.W. & Sheu C. 2002. A model for reverse logistics entry by third-party providers. *Omega* 30(5): 325-333.

Kuo, T.C. 2006. Enhancing disassembly and recycling planning using life-cycle analysis. *Robotics and Computer-Integrated Manufacturing* 22: 420–428.

Lowe, D. & Leiringer 2006 (eds). *Commercial management of projects: defining the discipline*. Oxford: Blackwell.

Pochampally, K.K. & Gupta, S.M. 2005. Strategic planning of a reverse supply chain network. *International Journal of Integrated Supply Management* 1(4): 421-441.

Rao, A., Jha, K.N. & Misra, S. 2007. Use of aggregates from recycled construction and demolition waste in concrete. *Resources, Conservation and Recycling* 50: 71–81.

Schultmann, F., Zumkeller, M. & Rentz, O. 2006. Modeling reverse logistic tasks within closed-loop supply chains: An example from the automotive industry. European Journal of Operational Research 171: 1033-1050.

Schultmann, F. & Sunke, N. 2006. Closed-loop oriented project management in construction - An approach for sustainable construction management. *Proceedings of the Conference Rethinking Sustainable Construction 2006, 19-22 September 2006, Sarasota, USA.*

Srivastava, S.K. & Svrivastava R.K. 2006. Managing product returns for reverse logistics. *International Journal of Physical Distribution & Logistics Management* 36(7): 524-546.

Stock, J. 1998. *Development and Implementation of Reverse Logistics Programs*. Council of Logistics Management, USA.

Srivastava, S.K. 2007. Green supply-chain management: A state-of-the-art literature review. *International Journal of Management Reviews* 9(1): 53-80.

Tam, V.W.Y. & Tam, C.M. 2006. A review on the viable technology for construction waste recycling. *Resources, Conservation and Recycling* 47: 209–221.

Thierry, M., Salomon, M., van Nunen, J. & van Wassenhove, L. 1995. Strategic issues of product recovery management. California Management Review 37(2): 114-135.

Thormark, C. 2000. Including recycling potential in energy use into the life-cycle of buildings. *Building Research & Information* 28(3): 176–183.

Tibben-Lemke, R.S. 2002. Life after death: reverse logistics and the product life cycle. *International Journal of Physical Distribution & Logistics Management* 32(3): 223-244.

Walther, G. & Spengler, T. 2005. Impact of WEEE-directive on Reverse Logistics in Germany. *International Journal of Physical Distribution and Logistics Management* 35(5): 337-361.

Wu, Y.-C. & Cheng, W.-P. 2006. Reverse logistics in the publishing industry: China, Hong Kong, and Taiwan. *International Journal of Physical Distribution & Logistics Management* 36(7): 507-523.

Overview of deconstruction activities in Portugal

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ABSTRACT: Deconstruction emphasizes promotion of "reuse" of building materials and components (and even whole buildings) as a way to "close the loop" of materials, and avoid the loss of matter and energy through construction and demolition waste. In Portugal, although there are various efforts to promote sustainability in the field of reuse and recycling of building materials and components, these are not yet united under the conceptual framework of Deconstruction. This paper presents an overview of these activities (selective demolition, building and component reuse), alongside a description of construction and design trends in an attempt to define a possible framework for deconstruction. This paper is part of an ongoing PhD research that aims to assess the possibilities of implementation of Deconstruction, from an architectural point of view, within the specific characteristics of Portuguese building design and construction industry.

1 INTRODUCTION

A vast amount of resources and energy is lost in building demolition and transformation, usually with associated negative environmental impacts due to considerable waste volumes produced. Building deconstruction allows a reduction of the negative impacts mentioned, by promoting the reuse of whole buildings, components or materials, both existing and future, thus increasing the efficiency of resources (material and energetic) in building construction.

The increase in environmental efficiency of the usage of resources is the ultimate aim in all sustainability efforts (UN-GASS, 1997), and recent studies have shown dissociation between GDP growth and Direct Material Inputs in several EU economies, in effect demonstrating that welfare can increase without resource consumption increase (Niza, 2001).

No report exists on Deconstruction activities in Portugal, as this subject has only recently became the object of scientific studies. This document follows the template for national reports used in CIB publication 300 *Deconstruction and Materials Reuse - An International Overview* (Chini, 2005), allowing easy cross-referencing with the various national reports.

1.1 *Waste statistics: overall production of C&D*

Construction and Demolition Waste (CDW) is still an undefined problem in Portugal, although awareness and need for research into its processing are rising. Presently, the most visible aspect of CDW is illegal roadside dumps, common along secondary roads or desert grounds. They are due to a variety of reasons including lack of appropriate dumps, insufficient inspection by authorities and particularly due to a general lack of awareness by parties involved (figure 1).

There are no quantified data on the type, origin and constitution of CDW in Portugal, other than local or incomplete studies. Data are difficult to obtain since there is a general lack of record keeping, while illegal dumping is rather commonplace.

Estimation of values ranges from 7.691 ton/year (Carvalho, 2001) to a 3 Mton/year production mentioned in the 1999 Symonds Report (Symonds, 1999), while more recent estimates provide a figure of 4,4 Mton/year (Farinha, 2007). Since there are no systematic and complete records, accurate trends are impossible to ascertain, but these last two values would represent a 150% increase in CDW production in less than ten years, and an average 400 kg/capita/year production.

Figure 1. Illegal Construction and demolition dump in abandoned factory in Lisbon

1.2 *Waste statistics: percentages of C&D waste reused, recycled or land filled.*

The Symonds report (Symonds, 1999) also indicated that, in 1999, less than 5% of all CDW in Portugal was reused or recycled, then one of the lowest values in the EU. The situation has changed little since then, although further CDW processing units have been created in the meantime. There are currently 31 licensed operators to receive and process CDW waste (INR, 2007), 67% of which act as basic landfill / separation units, while 13% act as valorization units for glass and ceramics. This amounts to an average of one unit per 2800 sq. km., a low value comparing to Germany's average of one unit per 223 sq. km. (Chini, 2005).

2 DEMOLITION AND DECONSTRUCTION TECHNIQUES, MACHINERY AND TOOLS

Before the second half of the XX century, buildings in Portugal were made essentially with load bearing walls, either of stonework or more often of a poorer mix of small stones, bricks and lime mortar. Raised floors were built of wooden elements, as well as interior walls (plastered over). Roofs were built using wooden structures with clay tiles. Exterior finishes invariably included mortar renders, painted or with lime washes. In the northern parts of the country the percentage of use of stone was higher, including load bearing walls in solid stone or stone slate roofs. In the southern areas, earth rammed construction was very common. The beginning of the XX century saw the introduction of reinforced concrete in building construction, although this only became generally widespread by the 1950's. Typical mid-century residential and office buildings comprise reinforced concrete frame, single or cavity wall of ceramic bricks, finished in mortar renders with scarce stone facings. Dividing walls are also in ceramic brick, with embedded infrastructures. Window frames are either in wood or first-generation aluminum, while roofs are composed of clay roof tiles over concrete structure or slab. The probable candidates for demolition or deconstruction are therefore extremely monolithic constructions, in which almost all elements are interconnected by chemical bonds, and where the possibility of disassembly and material harvesting is very low.

In April 2007 there are 42 registered demolition companies, ranging from family owned businesses to more professional multi-firm corporations, largely concentrated around Lisbon (13 firms) and Porto (9). The range of techniques used in demolition / deconstruction is thus quite limited, varying only due to the size and height of the building and the conditions of the location. Usually the first step is the removal of the more characteristic or valuable features (depending on the age of the building) whose form of fixing, size or value allows removal. Demolition work will take a top-down approach, using pneumatic hammers or hydraulic claws, handheld or as machine extensions, steadily demolishing the building on site. Demolition by controlled explosions is quite rare due to the fact that urban centers with older buildings are very dense areas, and explosive demolitions are liable to cause damage to adjacent buildings by blast or falling elements. Demolition thus results in largely mixed heaps of material (figure 2), with the material being carried to dumps (where some separation may take place, especially if metallic elements are present).

Several large-scale demolition operations have been undertaken in recent years, producing valuable experiences and learning. The former industrial area of the EXPO 98 site was totally cleared resulting in 750.000 tons of crushed concrete used in provisional roads and as a base layer for final roads, 100.000 tons of masonry rubble used for soil stabilization and 100.000 sqm. of existing granite paving blocks reused in the exhibition grounds (BIE, 1999). More recently, a considerable number of buildings were demolished in the Cacém "Pólis" urban renewal program, following very detailed work plans, listing demolition types and techniques, establishing principles for component salvage and demolition waste processing / reuse. (Morujão, 2003)

Figure 2. Typical early XX century building under demolition in Lisbon. Notice large percentage of soil content, with mixed metal, stone and wood elements

3 DESIGN FOR REUSE

3.1 *In situ building reuse*

There is a large tradition of whole building reuse in Portugal, especially large and medium scale built heritage. This habit can be traced back to the early XVIII century when the extinction of the religious orders left hundreds of monasteries and convents empty. These were gradually appropriated for other uses such as universities, military and police garrisons, hospitals, ministries and even the National Assembly. Considering their heritage value, they continue to be adapted to a variety of functions (museums, hotels, etc.).

There are also various examples of whole building reuse of more recent buildings (XX century stock), especially in urban centers. These operations include use change (offices to hotels, offices to hospitals), building growth (adding floors) or building remodelling ("facelift").

Nevertheless new construction prevails over refurbishment works as new building construction takes up 36% of the overall yearly investment in the construction sector, and remodeling and demolitions account for only 6% and 0,1% respectively. The development of territorial infrastructures accounts for 41% of the overall investment in the construction sector. Half of the investment in the building construction sector goes to housing construction (1,9 billion Euros / year), while the remaining half is essentially divided among the sectors of services, commerce and education (INE, 2005).

3.2 *Moving buildings*

Building transference is an almost unknown practice of which there are few examples. All constructions known to have been moved recently had steel structures, allowing disassembly and reassembly in a new location The pavilions that composed the southern section of the international exhibition area of Lisbon's Expo 98 were sold after the Expo end to a variety of locations in Southern Portugal where they were rebuilt as smaller exhibition structures, while Portugal's national pavilion in Hanover's Expo 2000 was reassembled in Coimbra. These processes were undocumented and no technical, economical or environmental profitability studies were undertaken. In March 2005, the former Macao Pavilion at Expo 98 was disassembled for rebuilding in the new Loures town park. This process is yet unfinished but is the subject of an undergoing study by the author, whose preliminary conclusions point to economic parity with a new structure, with a positive environmental balance (figure 3).

Figure 3. Former Macao Pavilion being reassembled in Loures (April 2007)

3.3 *Component reuse*

As mentioned earlier, harvesting of components from historical buildings is fairly common (including theft from abandoned buildings), as these decorative elements are widely reused in refurbishment projects or by interior designers seeking to achieve a traditional / ancient look.

Component reuse from more recent buildings is quite rare, as these often do not have aesthetic appeal, are not economically competitive with new comparable components and are generally unavailable when needed or wanted. There are rare cases of component reuse in the context of agreements between different firms, exchanging materials for workforce, or using materials as payment. One such case was the use of materials and components from the interiors of an existing office building in Lisbon in the new siege of an engineering company in Sintra.

The author, focusing on financial and environmental profits gained, is currently studying this project. A variety of circumstances contributed to this exceptional case (the "harvesting" company was about to change facilities, the materials were compatible with the ongoing project for the new site, and transport distances were very short), and while technical difficulties occurred, this was an overall successful project, attaining a reused material incorporation of 20% (figure 4).

Figure 4. Work in progress at the new IP offices in Cacém (March 2006). Doors, wood veneer wall panels and all lighting fixtures were being reused after disassembly from original location in Lisbon.

4 ENHANCING MATERIALS RECICLABILITY

Material separation for recycling is already a widespread practice concerning household waste, resulting in large quantities of salvaged paper, plastic and glass. Several other specific waste streams have also been the object of attention (hospital waste, farming waste, used vehicles) but CDW has largely been ignored and thus recycling of specific materials associated particularly with the construction industry is still very low and undeveloped, although the situation is slowly changing.

All CDW sorted materials that can be processed via other waste streams (plastics, metals, glass, and paper) are already almost fully recovered, while wooden materials are primarily used as fuel. But, given the prevailing construction habits in Portugal, with a predominance of reinforced concrete structures and a high percentage of ceramics in exterior and infill walls and in interior finishes, the largest percentage of CDW is composed of these types of materials, and these are the waste flows where greater effort is now required. Also worthy of mention are the remains from stone quarrying, in which up to 90% of extracted material is waste, and which cause serious environmental issues.

Current scientific research has focused mainly on recycled aggregate reuse, including in reinforced concrete, with recently issued legislation allowing for reuse in a variety of applications (LNEC, 2006). A potentially very beneficial recycling issue would be the use of crushed ceramic materials (including gypsum boards) as a secondary raw material, replacing virgin materials in clinker due to high silica and lime content (Hendriks, 2001). This could prove a quite important measure as Portugal is one of Europe's largest consumers of cement, with one of the highest per capita values in Europe (CEMBUREAU, 2004), and the resource extraction associated with cement production has major environmental impacts, hotly contested by populations.

The WAMBUCO - Waste Manual for Building Construction research project was recently completed, encompassing contributions from several other European countries (CEIFA, 2005). The purpose of this manual is to provide an easy usable method to estimate waste generation from building construction activities, be it a new building or a remodeling. This manual, although not yet available to the general public, could work as a good base for enhancing material reciclability by allowing a timely organization of CDW flow processing and management.

5 ECONOMICS OF DECONSTRUCTION AND MARKETING OF USED BUILDING MATERIALS

Since there is little demand, there is also little supply, and thus it is difficult to define market dynamics of reused building materials and components. As mentioned earlier, contemporary component disassembly is quite rare and usually motivated by very specific conditions. In the context of the study of material harvesting between interior projects mentioned on chapter 3.2, the cost of disassembly and transportation represented 50/60% of the price that the materials recovered would cost as new. This is considered a rather high value, probably exceptional in the context of a more generalized reused materials and components market.

6 DESIGN OF BUILDINGS AND COMPONENTS FOR DECONSTRUCTION

The link between design community and building industry is not very strong in Portugal, leading to the existence of very few initiatives for product development initiated from the design community. Current architectural design methodologies do not contemplate deconstruction as an objective, especially since not even maintenance needs are adequately considered or catered for, and a long default service life is assumed independently of building type. Energetic performance is slowly reaching the top of design priorities and it can be considered that this will probably hinder future deconstruction on current buildings as the performance demands of the new 2006 RCCTE (Building Energetic Performance Regulations) will lead to a generalized use of continuous exterior insulation, as ETICS or projected PU, rendering future material separation of building skins even more difficult if not impossible.

The revision proposal of the RGEU National General Building Codes proposes to establish a minimum service life of 50 years for buildings, which may already be out of tune with present building average lifetime, but which probably will raise the issues of adaptability and flexibility. The promotion of these last two parameters by building layers dissociation and adoption of adequate technical constructive solutions will probably be the most promising road for deconstruction in Portugal, further promoting whole building reuse (already an historical habit). However this will require informing architects and designers, which are for the vast majority unfamiliar with open building principles, still tailoring buildings for a given program without other use scenarios, even on very fast changing programs. DGIES - General Directorate for Health Facilities and Equipments - is already trying to find a solution to the high rate of spatial and facilities change in hospitals, and has had a recent workshop with Dr. Stephen Kendall to acquaint itself with "Open Building" principles, based on deconstruction logics (Kendall, 2002).

7 BARRIERS AND OPPORTUNITIES FOR DECONSTRUCTION

7.1 *Barriers*

As Portugal still has (apparently) considerable natural resources, and CDW is not yet perceived as a real problem. So there is no real motivation for adoption of deconstruction, other than a social or ecological awareness based one.

Government efforts have been put into Municipal Solid Waste prevention and processing, thus CDW is not yet perceived in its full dimensions (waste, energy and materials loss) and legal framework does not promote or enforce deconstruction. No specific regulations exist yet regarding CDW, although more general laws mention CDW and Best Environmental Processing Option "ladders" are in print. There are no legal obligations or tax benefits from building materials component reuse or donation, other than profits gained from sorted materials sold for recycling and as dumping fees at landfills are still quite low (from 1 euro/ton to 60 euro/ton), companies prefer dumping to disassembly (in the cases when it was possible).

There is no "take back" policy on building materials, so the producers have no responsibility for their products. The only known exception is the SIKA Company, which provides a take back service on their PVC waterproofing membranes, be it new construction leftovers or materials recovered from demolitions and refurbishments. Provided materials are uncontaminated and transported to its facilities in Switzerland.

No legal obstacle exists to building components reuse except that they must comply with prevailing regulations, namely fire safety, insulation performance and structural performance. This effectively limits component reuse to decorative and finishing materials or spatial configuration elements.

Public tender rules allow contractors to submit alternatives for specified materials, so it will be difficult for an architect to enforce the use of reused elements. The more plausible way of reused components finding their way to reuse would be in "design-build" tenders where the team dynamics could be more favorable. Nevertheless, the recent adoption of laws demanding that all materials used in public works be certified will make it more difficult to adopt reused materials and components, as there is no body or responsible for its reappraisal.

7.2 *Opportunities*

The high dependency on oil imports, a growing social and political awareness of the negative impacts of current consumption patterns will progressively lead to a change of perception towards material and component reuse, providing the legal framework that both permits and stimulates the adoption of these logics by the market.

The high percentage of new building construction could be used to produce a large stock of more deconstruction friendly buildings if adequate information was spread quickly enough, even considering current prevailing building "heavy and wet" matrixes.

Certain demographic sensitive programs such as primary schools, or primary health centers could benefit from pro-deconstruction projects allowing changes in the buildings size without long and costly adaptation works, or without being abandoned.

8 FURTHER RESEARCH

More accurate CDW quantification is needed and is already undergoing, which will allow the general public to perceive the dimension of the problem. Concurrently, studies must be made to evaluate the possibilities and benefits of deconstruction (demolition vs. disassembly, new building vs. reuse) specifically in the Portuguese context, demonstrating both the economical and environmental feasibility of such operations. The concept of deconstruction must be divulged, especially near the concerned actors, including students, via manuals such as SEDA - Design and Detailing for Deconsctruction, framing deconstruction into the broader objective of sustainability and laying foundations for the adoption of principles compatible with Portuguese standards and practice.

9 CONCLUSION

Deconstruction is virtually unknown in Portugal, as there seems to be need for it, and construction matrixes in Portugal are historically and currently unsuitable for building disassembly. Nevertheless, consumption patterns are highly unsustainable and must be addressed urgently, including the construction industry that has an important role to play in this change due to its expressive contribution to economic activities.

REFERENCES

ParquExpo. 1999. *EXPO 98 Final Report to Bureau International d' Expositions*. Lisbon

Carvalho, P. L. G. 2001. *Managing Construction Industry Waste.* MsC Thesis, Instituto Superior Técnico. Technical University of Lisbon. Lisbon

CEIFA. 2005. *WAMBUCO - Waste Manual for Building Construction.* Vols. I & III. Lisbon.

CEMBUREAU. 2004. *Activity Report 2004*. http://www.cembureau.be acessed January 10th, 2007

Chini, A. (ed.) 2005. *Deconstruction and Materials Reuse - An International Overview*. CIB Pub. 300.

Symonds Group Ltd. 1999. *Construction and Demolition Waste management practices and their economic impacts - Final Report to DG XI European Commission*

Farinha, P. 2007. Portugal com 4,4 milhões de resíduos anuais provenientes da construção. In *Público Suplemento Imobiliário* April 6th 2007

Hendriks, F. 2000. *The Building Cycle*. Aeneas Publishers. Netherlands

Kendall, S., 2002, *Open Building: a New paradigm for health care architecture - The INO Hospital*. Building Futures Institute Study Mission Report.

Morgan, C.. 2005. *Design and Detailing for Deconstruction*, SEDA Design Guides.

Morujão, P. 2003. *Projecto de Demolição das Construções existentes na zona de intervenção do*

Programa Pólis - Memória Descritiva - Parte I - Enquadramento, métodos de demolição e actividade de empreitada, document 200.23.DEM.PE.MM.001.

Niza, S. 2006. "A transitional economy's metabolism: the case of Portugal" in *Resources, Conservation and Recycling*, 46 (2006): 265-280.

Waste Institute website: http://www.inresiduos.pt

Salvageability of building materials

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ABSTRACT: In the context of reducing environmental impact of constructions by facilitating salvage of building components and materials, the term Design for Disassembly (DfD) is commonly discussed. However, in the different sets of guidelines describing how to design reusable and recyclable buildings, more aspects of the design are stressed. Components should be prepared for all the stages of the salvaging process, including sorting, transport, new design and reassembly. The paper presents a comprehensive systematisation of the DfD principles. The aim is to make up a clear, pedagogic system, as well as to link the design principles to an assessment tool. Also, the system can function as a checklist when designing salvageable materials and components. The paper concludes that since many design aspects are relevant in facilitating the salvaging of building components, the term *design for disassembly* is misleading, and could be replaced by the term *design for salvageability.*

1 INTRODUCTION

1.1 *DfD guideline compilations*

Solutions for environmental challenges in general and for climatic changes in particular are frequently and increasingly debated. The building industry has put much focus on reducing energy demands during user phase of constructions, and a new building code imposing even stricter U-values has recently caused fury among architects and builders in Norway. However, when it comes to greenhouse gas emissions, Norwegian statistics show that a greater part originates in the production of building materials (Byggemiljø 2007). This raises the question of a possible shift of focus to material production, transport, use and considerations in demolishing phase. Since much of the environmental effort that has been invested in the production of building material can be salvaged through reuse and recycling, the demand for salvaged building material is believed to increase in a not too distant future.

Design for Disassembly (DfD) is discussed in a number of studies as a line of action in reducing environmental impact of building constructions. When focusing on durable components and flexible design, several service lives are seen as feasible. With the strategy of DfD there will presumably be less pressure on new material resources and reduced waste, in spite of the increasing turnover of buildings. Several researchers have presented lists of design principles or guidelines for DfD. A brief description of the selected compilations of guidelines is given (chronologically) below:

Bjørn Berge (Berge 2000, p.12-14) describes three principles of *ADISA (assembly for disassembly)*, which are: *separate layers, possibilities for disassembly within each layer,* and *use of standardized monomaterial components*. The three principles comprise some details in implementation and reasoning.

Scot Fletcher (Fletcher 2001, p.96-99) classifies a total of 37 DfD guidelines into three levels: *systems level* (adaptable buildings which can change to suit changing requirements), *product level* (element manufacture/ construction which allows upgrading, repair and replacement) and *material level* (reuse, recycling and the natural degradation of materials). The *systems* guidelines are further subdivided into four sections under the headings: *design, information, market and disassembly*.

Catarina Thormark (Thormark 2001, p.68) structures 18 design guidelines into three groups: *choice of materials, design of construction* and *choice of joints and connections*. A separate column in the table gives reasons for the guidelines.

Paola Sassi (Sassi 2002, p.3) focuses on two main areas: 1/ *the process of removal of building elements and materials from building structure* and 2/ *the requirements for reprocessing of building elements and materials to enable reintegration in a new building*. Within these areas the following points are further described: 1/ *information, access, dismantling process, hazards, time,* and 2/ *reprocessing, hazards, durability* and *information*.

Philip Crowther (Crowther 2003, p.200-201) relates 27 DfD principles to five generative fields of knowledge: *industrial design, architectural technology, buildability, maintenance* and *research*. Furthermore the principles are connected to the hierarchy of recycling (p.300-301) in a separate table. The reasoning for the selection of principles and for their classification is elaborated in separate sections.

The CIRIA guide by W. Addis and J. Schouten (CIRIA 2004, p.26) synthesizes 19 principles (based on Crowther), and relate these principles to their desired outcome: *component reuse, component manufacture* and *material recycling*.

The SEDA guide by C. Morgan and F. Stevenson (SEDA 2005, p.23) summarises seven principles for deconstruction detailing. The design implementation and the reasoning are further elaborated in the following sections.

Elma Durmisevic (Durmisevic 2006, p.272-274) lists a total of 37 DfD guidelines, and relate these to three levels (*building, system* and *material* level) within three life cycle coordination scenarios: scenario 1/ *use life cycle* < *technical life cycle*, scenario 2/ *use life cycle* > *technical life cycle,* and scenario 3/ *use life cycle = technical life cycle*. A particular focus is set on design configurations that facilitate disassembly.

The classification systems of these lists as well as the level of detail and the number of points vary. Some studies also explain the specific reason(s) for each principle, and link the principles to their desired outcome. However, the overall aim is more or less the same: material resource efficiency through facilitating reuse and recycling.

1.2 *Characterisation and classification of principles*

The characters of the principles may be divided in three groups:

- Behavioral statements that deal with values and general environmental goals
- Performance standards that are more explicit in their aim and offer specific targets of achievement
- Prescriptive guidelines that offer the designer the most direction in achieving an aim (See Crowther 2003, p.167-168 for further explanation).

All the surveyed lists express, as a behavioral statement, environmental material resource management as the final goal. The lists with few points usually consist of performance standards that are later elaborated in text. The lists with a greater number of points usually consist of prescriptive guidelines that give detailed design information. The characters of the principles are sometimes also mixed within one single list.

The varying classification systems of these lists are keys for understanding their similarities and differences. The guidelines may be classified according to:

- Type of technical benefit such as ease of handling or ease of sorting
- Scale of application such as materials, joints, and overall structure
- Technical level of reuse, such as material recycling, component reuse, and building relocation (See Crowther 2003, p. 297-298 for further explanation).

There are examples of all these classification systems in the surveyed guideline lists. Some of the lists combine two systems so that the principles are related to e.g. both scale of application and technical benefit. Also, some lists give reasons for the guidelines so that the link to their benefit becomes clearer. The question is what the appropriate classification system for an overall systematisation of the DfD guidelines could be.

One may ask if there is a need for yet another list of guidelines. What we do lack however, is a comprehensive system with a consistent and explanatory layout. This system should clarify different levels of scale and be linked with technical benefits (at an intermediate level) as well as with the purpose/ objective of each principle.

1.3 *From guidelines to assessment tools*

Some studies present DfD assessment methods as well as lists of design guidelines. A brief description of three methods is given (chronologically) below:

Catarina Thormark (Thormark 2001, p.70) gives an outline of a method for assessment of the *ease of disassembly*. Assessed parameters for the purpose of *reuse* are: *risks in the working environment, time requirement, tools / equipment, access to joints,* and *damage to the material caused by disassembly*. As this is an outline for a method only, for the purpose of *material recycling* and *combustion*, relevant parameters are to be filled in. The possible scores are distributed evenly among the parameters.

Paola Sassi (Sassi 2002, p.4) presents a method for assessment of *suitability for reuse/ recycling/ down-cycling* that is based on more than 60 case studies on building products and construction methods. Parameters are divided into *cost*- and *technically* linked criteria, listed according to the goal for the disassembly. Assessed parameters for the purpose of *general dismantling* are: *installation systems and fixing methods, access to and handling of building elements, hazards (toxins, structural, handling), time required to dismantle elements,* and *information required to dismantle elements*. Assessed parameters for the purpose of *reuse as second hand item* are: *reprocessing requirements to enable reuse, durability, components and subcomponents, hazards, requirements for performance compliance, information required for reinstallation,* and *fixings required for reinstallation*. Assessed parameter for the purpose of *reuse as new (ADDITIONAL criteria)* is: *requirements to ensure aesthetic standard*. Finally, the assessed parameters for the purpose of *down-cycling* and *recycling* (assessed separately) are: *reprocessing requirements, durability,* and *hazards*. The technically linked criteria are given a higher weighting and consequently a higher possible score than the cost linked criteria. Except for this, the possible scores are distributed evenly among the criteria.

Elma Durmisevic (Durmisevic 2006, p.203-212) introduces a knowledge model for assessing *Transformation Capacity (TC)* of structures. The method is implemented in case studies on an office building and a facade-system, and in three case-studies of inner wall constructions. The focus is on *disassembly potential* (General dismantling) only, and the model is divided into four levels of abstraction. The two main indicators are *independence* and *exchangeability*. At an intermediate level these are further divided into a *material,* a *technical,* and a *physical level of decomposition*. As sub aspects are listed *functional decomposition, systematization, base elements, life cycle coordination, relational pattern, assembly process, geometry,* and *connections.* Finally, the input-level consists of 17 determining factors, that each receives an even amount of possible score.

The assessed parameters in all these three tools are classified according to the objective for the disassembly. The objectives refer to the recycling hierarchy, and include:

- General dismantling
- Reuse
- Material recycling
- Combustion

However, there is generally no direct connection between the specific design guidelines and the assessed parameters. Sassi's parameters do correspond more or less to a predefined set of criteria, but these are, however, expressed as performance standards rather than as specific guidelines. This means that the evaluation will be performed at an intermediate level, which may open for a high degree of interpretation.

We would like to investigate if the traceability of the assessment can become more apparent by applying the specific guidelines directly in the method. We therefore suggest the possibility of transforming the overall system for DfD guidelines to an assessment tool. In this way we will achieve a direct link between the guidelines and the assessed parameters.

2 SUGGESTED SYSTEMATISATION

2.1 *Multi-purpose system*

The aim of the overall systematisation of the guidelines is threefold: It should make up a clear, pedagogic system suitable for communicating both the basic points and the details of the principles to architects and others involved in the building design process. Secondly, the system should be convertible to an assessment tool to be used when choosing building components for a new design with respect to their potential at the stage of deconstruction. Also, the system could function as a checklist when designing salvageable materials and components.

The design guidelines are classified by combining the three systems of classification previously described (Fig. 1). Since the principles are relevant at different scales of application regarding construction, it is suggested to first arrange them at a *component*-, a *construction*- and an *industry*-level of *scale*. The component- and construction-level focus on building design, while the industry-level focuses on legal and financial aspects that represent constraints for the building industry. In an intermediate section, each level consists of relevant *criteria* that describe the core points of a group of design *strategies*. The criteria are expressed as performance standards, whereas the strategies themselves describe how to achieve these standards. Some criteria are relevant at more than one level. For instance the theme *information* is relevant at all three levels, but addresses different topics. At the component- level; tagging of materials and components, at the construction- level; updated as-built drawings and guidance for deconstruction, and at the industry- level; dissemination of knowledge to designers and builders. The strategies can further be connected to their primary *objectives*, which may be *maintenance, adaptation, building relocation, reuse of components* or *material recycling*. Through these objectives, salvage of building material will presumably be achieved, which in turn aims at the more general goal of resource efficiency and overall sustainability.

The objective column of the scheme shows that each strategy may have relevance for one or more objectives. Besides the visualization of the relevance of each strategy, a weighting of importance can also be performed. Not all strategies for a criterion are necessarily relevant in each case even though listed in the overall scheme, whereas others may be highly stressed. The result will also depend on goals and priority-setting of the users. Thus, the complementing of the matrix could be subject for a study on its own, and the spaces are therefore left blank at this point.

The next step is the transformation into an assessment tool. The reasoning for the specific principles can help singling out the relevant guidelines for each assessment. In a case study on massive wood construction components (Nordby et al. 2007b), the principles that are relevant for assessing the reusability of whole components are collected and weighted for use in this particular context. The assessment thus represents a pilot study of using the design guidelines directly for an evaluation of building constructions.

2.2 *Prioritizing themes*

From the surveyed compilations, a set of strategies has been selected. Naturally, some strategies are more basic than others. The strategy *use mechanical not chemical connections* is included in all the surveyed lists in one form or the other. Actually, there are several physical levels where this strategy may apply; when materials are joined together to form a component, when components are joined together to form a building layer or constructional part, and when constructional parts are joined together to form a building. For this reason, the criterion *flexible connections* is relevant at both the component- and construction-level.

It is widely recognized that it should be possible not only to disassemble components and constructions, they should also be prepared for the other stages of the salvaging process, including sorting, transport, new design and reassembly. The remaining criteria at the component- and construction-level of scale reflect these other desired characteristics: A *limited material and component selection* simplifies dismantling and sorting and enables quality control of components before reuse. *Durable design* facilitates dismantling and reassembly, and increases the amount of components suitable for reuse. A *layered construction* will grant structurally independent and exchangeable building parts. *High generality* of components and constructions makes reuse more probable because of the architectural flexibility for a second service life. Finally, *information and access* facilitates the planning of dismantling and the dismantling proc-

S A L V A G E A B I L I T Y Anne Sigrid Nordby, 23.04.2007

SCALE	CRITERIA	STRATEGIES	Maintenance	Adaptation	Relocation	Reuse	Recycling
Component	Limited material selection	1. Minimise the number of different types of materials in component, including connections for sub-assemblies					
		2. Plan for using a minimum number of connectors and of different types of connectors between components					
		3. Avoid secondary finishes					
		4. Avoid toxic and hazardous materials					
	Durable design	5. Design durable components that can withstand repeated use and outlast generations of buildings					
		6. Provide adequate tolerances for repeated disassembly and reassembly					
	High generality	7. Aim for standard dimensions and modular design					
		8. Aim for small scale and lightweight components					
		9. Reduce the complexity of components, and plan for using common tools and equipment					
	Flexible connections	10. Use reversible connections for subassemblies					
		11. Plan for using reversible connections between components					
		12. Allow for parallel disassembly of components					
	Information and access	13. Provide identification of material and component types					
		14. Identify and provide access to connection points					
Construction	Limited component selection	15. Minimise the number of components and of different types of components					
		16. Minimise the number of connectors and of different types of connectors					
	Layered construction	17. Design a layered construction with structurally independent systems					
		18. Arrange the layers according to the expected functional and technical life-cycles of the components					
	High generality	19. Aim for modular construction and use a standard structural grid					
		20. Reduce the complexity of constructions, and plan for using common tools and equipment					
	Flexible connections	21. Use mechanical not chemical connections between building parts					
		22. Allow for parallel disassembly					
		23. Design joints to withstand repeated use					
	Information and access	24. Identify and provide access to connection points					
		25. Provide updated as-built drawings, log of materials used and guidance for deconstruction					
Industry	LC-supportive legislation	26. Introduce/ reinforce landfill-tax or -ban which limits/ prohibits the land-filling of salvageable construction and demolition waste					
		27. Introduce/ reinforce construction regulations which address life cycle design					
	Financial incentives	28. Support the use of salvageable materials and constructions					
		29. Support research and development of salvageable designs					
	Substantiated Information	30. Provide dissemination of knowledge to designers and builders of the environmental, social and economic benefits of salvageability					
		31. Provide quantification of economic benefits of salvageability in the life cycle of buildings					

OBJECTIVES: Maintenance, Adaptation, Relocation, Reuse, Recycling

Figure 1. Suggested systematisation of design guidelines for salvageability.

ess, and it also simplifies the sorting and reuse process. Most of these principles are found in the extensive compilation by Crowther, and their general benefits are thoroughly discussed there.

The criteria at the industry level describe the desired characteristics of a construction industry aimed at environmental efficient material resource management (see Sassi 2004). *Life-cycle supportive legislation* is today implemented to varying extents in different European countries, whereas *financial incentives* to support the use and development of flexible designs are probably best known through the IFD-programme of the Netherlands. *Substantiated information* about the benefits of salvageability should be disseminated to designers and builders along with the general knowledge about environmental solutions.

One guideline that is listed in several of the surveyed compilations is the *use of recycled materials*. The reason for this guideline is to support the recycling industry. In our understanding this action is not a strategy directly linked to achieving salvageability, but rather a principle that may be supported by financial incentives. This strategy therefore belongs at the industry level.

Avoiding toxic material is not defined as a separate criterion. The subject is relevant in sustainable construction, but not necessarily for salvageability. It should therefore be considered only if it disturbs the recycling processes, e.g. gives rise to health hazards in the work environment. For the reuse of whole components or relocation it is not necessarily relevant.

As far as production conditions are regarded, prefabrication is not considered a desired means in itself. Prefab building may imply, at least in a country like Norway, long transport distances including fuel emissions both in the building- and recycling processes. Therefore, the suggested guideline *use prefabrication* is omitted as a strategy. Focus is rather set on simple construction methods, small scale and lightweight components that can be manually handled, and the use of common tools. By facilitating local and also do-it-yourself building, local reuse is simultaneously facilitated, and environmentally this is the most beneficial strategy.

One criterion completely left out is *time use*. The time required to dismantle elements is crucial for the economical feasibility, and in the field of industrial design this parameter is usually heavily weighted. However, when discussing salvageability, the question of financial cost is not considered relevant. Focus is on environmental cost, which today is not consistently reflected in the economic system. Therefore, strategies that are purely cost-linked are omitted.

The presented systematization reflects the values and priorities of the authors. However, this list could be expanded to include other criteria and more strategies. The main point is that it can function as an overall scheme that relate the design strategies to *scale* of application, *criteria* at the intermediate level, and to the desired *objectives* according to the recycling hierarchy.

2.3 *Denomination*

Design for Disassembly and Design for Deconstruction are terms commonly applied when the aim is expressed as material resource efficiency through reuse and recycling. However, as this study shows, in the different sets of guidelines describing how to design reusable and recyclable buildings, more aspects of the design are usually stressed. Design aspects also relate to the processes of sorting, transport, new design and reassembly, and therefore the term Design for Disassembly can be perceived as confined and misleading. Our suggested replacement is *Design for Salvageability*. The intention of this expression is to include all lines of actions that contribute to salvage of building materials in one way or the other. Maintenance, adaptation and relocation of buildings are considered as possible objectives for the strategies, as well as component reuse and material recycling. It is, however, possible to tailor a more specific term within the concept of salvageability; e.g. when reuse of whole components is considered a prioritized target, the term would be Design for Reusability.

3 DISCUSSION

Different lines of action may lead to enhancing the environmental performance of building construction, and Design for salvageability is one of them. The proposed systematisation of guidelines defines criteria that can lead to environmental advantages assuming that there is no sub-optimization. The strategies should therefore be checked against other environmental concerns.

The scheme relates the design strategies with:

- Levels addressing *scale* of application
- Operational *criteria* at the intermediate level
- Desired *objectives* according to the recycling hierarchy

When used as an assessment tool, the relevant strategies that relate to the objective of each assessment can be singled out and adequately weighted.

The fact that the same strategy can facilitate different objectives as well as support different overall goals can be confusing. Some of the criteria, like flexible connections, will facilitate all the listed objectives. In addition, flexible connections may be a means to user flexibility which can result in added value of the property. The objectives in the scheme are structured according to the recycling hierarchy, which indicate that some options are more environmentally sound than others. Reuse is considered a better choice than recycling because less processing means less energy spent and less emission released; hence the total environmental burden is less. The highest level in the hierarchy is considered to be maintenance, because frequent care saves the building from deteriorating with a minimum of environmental (as well as financial and practical) effort (Brand 1994).

Whereas the objectives of preparing buildings for adaptation and maintenance are now being performed because these benefits are in demand by clients (Sassi 2004), the objective of preparing buildings for relocation is usually reserved for temporary applications like school pavilions and exhibition spaces. The preparation for recycling and reuse, however, is mainly focusing on environmental gain, and will probably not be extensively performed as long as the financial and legislative constraints are designed to support short-term financial profit rather than sustainability in the life cycle of buildings.

REFERENCES

Addis, W. & Schouten, J. 2004. *Principles of design for deconstruction to facilitate reuse and recycling*. London, CIRIA books.

Berge, B. 2000. *Ecology of building materials.* Oxford Architectural Press.

Brand, S. 1994. *How buildings learn.* New York, Penguin books.

Byggemiljø 2007. *Innspill til sektorvis klimahandlingsplan for byggsektoren*. Byggenæringens miljøsekretariat. Available from: http://www.byggemiljo.no/

Crowther, P. 2003. *Design for Disassembly.* Thesis, Queensland University of Technology.

Durmisevic, E. 2006. *Transformable building structures*. Thesis, University of Delft.

Fletcher, S. L. 2001. *Developing disassembly strategies for buildings to reduce the lifetime environmental impacts by applying a systems approach*. Thesis, University of Sheffield.

Nordby A. S. et al. 2007b. Reusability of massive wood components. *Paper submitted for SB07 conference in Lisbon: Sustainable construction, materials and practices.*

Sassi, P. 2002. *Study of current building methods and products that enable dismantling and their classification according to their ability to be reused, recycled or downcycled*. International Conference for Sustainable Building, Oslo.

Sassi, P. 2004. Designing buildings to close the material resource loop. *Engineering sustainability* 157, Sept. 04, Issue ES3, p. 163-171

SEDA 2005. *Design and detailing for deconstruction – Design guide for Scotland*. Scottish Ecological Design Association. Available from: www.seda2.org/dfd/refer.htm

Thormark, C. 2001. *Recycling Potential and Design for Disassembly in Buildings*. Thesis, Lund University.

Reusability of massive wood components

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ABSTRACT: Massive wood is considered to be an environmentally beneficial building material, however it is not common to design components for a second service life. In a case study, we investigate how the component design influences the reusability. The criteria used are: *limited material selection, durable design, high generality, flexible connections*, and *access and information.* Five Norwegian massive wood constructions are compared: log construction representing the vernacular tradition, customized massive wood components manufactured by Moelven and Holz 100 representing presently used component types, and the modular massive wood components of Valdres Tremiljø and "Klimablokken" representing innovative designs, the latter still at the prototype stage. The results indicate that there are great potentials to improve the reusability for the most commonly used components types. Improved generality of the components will give architectural flexibility in a second service life, which is crucial to increase the likelihood of reuse.

1 INTRODUCTION

1.1 *Material resource efficiency*

The Norwegian building industry suffers from a poor material resource management. This is reflected, among other factors, through a low percentage of reuse and recycling of building materials. Coupled with high activity, the negative environmental consequences are found in both ends of the material flow, and consist of increased pressure on new raw material as well as of growing landfills with toxic emissions. Also, on the way from cradle to grave, the processing and transport of materials consume large amounts of energy.

A suggested strategy for reducing these negative impacts is to facilitate the use of durable and flexible components that can be used for generations of buildings (Berge 2000). A high environmental input in the production of building materials can be regarded as an investment, and should be reflected in a correspondingly long component lifetime, or environmental payback time (Nordby et al. 2006). Furthermore, seeing that we often get a mismatch between the long technical lifetime of components and the short service life of a building or of a building layer, building components should be prepared for probable alterations. In spite of the fact that building turnover generally is increasing, this strategy would result in greater resource efficiency because the components could enter a number of different building configurations. Important, however, in achieving closed loop material cycles is to design the components and constructions in ways that make salvage not only feasible, but advantageous.

Vernacular building methods are often highlighted as being resource efficient, a characteristic that also may include reusability. Brick buildings from the 1920s and earlier are usually laid with lime mortar, which makes deconstruction feasible. Since bricks are very durable they have commonly been reused in new constructions. Also timber constructions were designed for disassembly and reuse. The traditional Norwegian log construction was prepared for both replacement of units, remodeling, and relocation. Often the house was a part of the luggage when a family moved from the countryside to a nearby town.

However, we have not brought these design principles into the contemporary building industry, and as a result the post-war building stock is not particularly salvageable. It appears as a setback when bricks carefully salvaged from buildings of the 1800s are reused in new walls and laid with cement mortar. The very reason it is feasible to deconstruct the old brick walls is the flexible lime mortar. With the solid cement mortar, one cannot assume that more future lifetimes are obtainable. Paradoxically, along with the development of advanced technology, the intelligence of the building methods that earlier supported flexibility and long life, has vanished.

1.2 *Wood as building material*

Wood as a construction material has long traditions in Norway, but the focus on wood as an ecologically preferable material is a relatively new notion. Anyway, the environmental rationale for using wood is many-sided: Firstly, wood is a renewable material with fairly low environmental impact in production. Since forestry is a widespread industry, timber is in most places harvested locally, and consequently energy use for transport is moderate. Wood is also highly versatile and can be used for almost all building elements, and designed in the right manner it may last for centuries. Secondly, the contribution of wooden surfaces to a healthy indoor environment is highlighted as an environmental benefit. The capability of storing heat as well as moisture helps balance the air quality. However, to achieve this it is important to avoid impermeable paints and varnishes.

Thirdly, one can argue that wooden components will delay the negative climatic effects through CO_2-storage. All growing biomass material transforms CO_2 from the air to glucose, and it will stay in this chemical bond till the material burns or decomposes. If more biomass material was used in building construction, the effects of the rising CO_2-content in the atmosphere could be moderated. This strategy would give mankind more time to find good solutions to the energy challenges. The argument of CO_2-storage is a point of particular interest regarding the use of massive wood because the material volumes involved in building are greater than in the more common wood framework. Massive wood components have been introduced during the last 20 years as a constructional alternative to concrete, promoted by sustainability issues as well as time efficient construction. Some component types combine structural capacity with good insulation qualities, and thereby it is possible to build complete insulated walls with simplified constructional operations. If parts of the Norwegian building mass were substituted with massive wood, we could achieve considerable reductions of CO_2.

When it comes to salvageability, wood has a great potential through a set of cascade chains that can extend the material's useful life, e.g. reusing of components, reprocessing into particle-boards, pulping to form paper products, and burning for energy recovery. It can be questioned, however, if down-cycling necessarily will lead to environmental benefit. Such procedures most often include transport as well as industrial processes that demand energy and release emissions and waste. The waste hierarchy therefore points to reuse of components as being preferable to recycling and recovery, as the material quality then is retained at a minimal environmental cost (Crowther 2003).

1.3 *Aim of research*

Since the reuse of timber constructions has long traditions in Norway, it seems timely to pursue these traditions in the context of sustainability, and forward them to industrialized building. Although our society may have other reasons for salvaging material than in earlier times and although the economic framework is quite different, the design of the components themselves remains an important parameter. Massive wood as a building material has a great potential of meeting challenges in a low carbon society, but the components generally lack reusability. For these reasons, we focus on *reuse* of *components* in a case study on *massive wood*. We wish to decompose the term reusability, and investigate exactly what factors that make a massive wood component reusable. The case study includes a traditional log construction and compares it with contemporary methods of massive wood. The aim is to investigate how the component design limits or supports the reusability. Since this is a pilot case study, the assessment method is also tested and commented.

2 ANALYSIS

2.1 *The assessment method*

The principles of salvageability (Nordby et al. 2007a) are converted to an assessment tool (fig.2). The criteria within the component-level of the system are: *limited material selection, durable design, high generality, flexible connections*, and *information and access*. The reasoning given for the specific strategies helps differentiating their importance for the assessment of massive wood components. We have assumed a relative importance that is shown with a number of x. Furthermore, we have given each strategy a maximum score that reflects relative importance within each criterion A total of 24 points are given to each criterion. These points can be easily distributed amongst the different numbers of strategies as well as amongst their relative importance.

Then each case is given scores for their qualities. The scores are (also) based on judgements made by the authors, and are subject to interpretations. However, a principle followed is that no score is given when desired characteristics are not present, and maximum score is given when the desired characteristics are fully present. In figure 3, combined scores for the different criteria are shown as clustered columns. The total number of points for each case object is not added up, because the criteria are considered to represent different aspects of reusability. These aspects may vary in importance from one assessment to the other.

2.2 *The selection of case study objects*

The reusability of five Norwegian massive-wood components is compared: Traditional log construction, customized massive wood components manufactured by Moelven and Holz 100, modular massive wood components manufactured by Valdres Tremiljø, and finally the modular concept "Klimablokken". Although the manufacturers Moelven and Holz 100 also provide modular components, we have chosen to include only the customized wall elements because those are the most commonly used, and also because that will give the selection of case objects a sufficient variety. Size, shape and connection methods are the most important parameters in separating the case objects. The selection thus represents a diversity of solutions: a vernacular building system, three presently used component types, and one innovative concept still at the prototype level. The functional unit is one typically sized wall component.

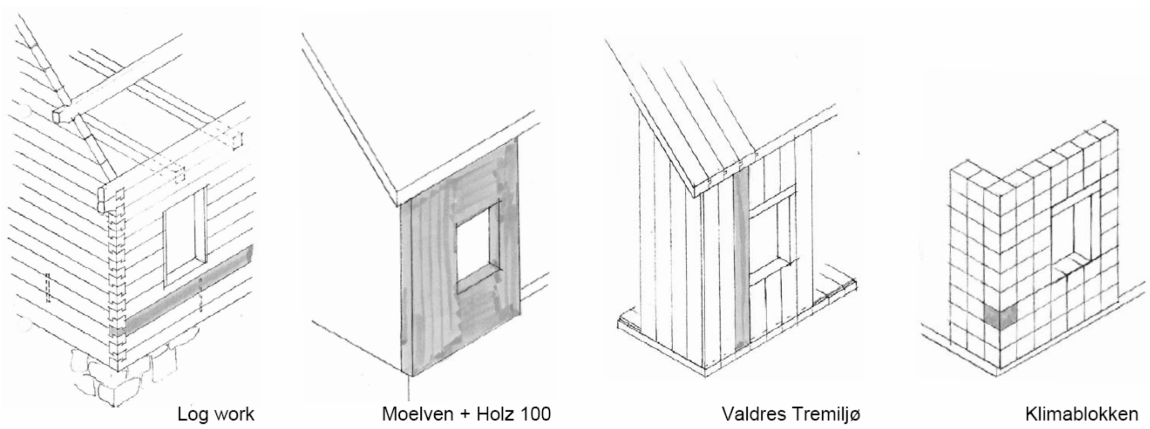

Figure 1. The case study objects, with the functional unit shaded.

2.3 *The results*

REUSABILITY OF MASSIVE WOOD COMPONENTS — Anne Sigrid Nordby, 22.04.2007

SCALE	CRITERIA	STRATEGIES	REASONING	Relative importance (for criteria)	Max score	Log work	Moelven	Holz 100	Valdres Tre	Klimablokk
Component	Limited material selection	1. Minimise the number of different types of materials in component, including connections for sub-assemblies.	• simplifies dismantling and sorting • simplifies quality-control of components before reuse • makes reuse more attractive due to greater number of fewer material types	xxxxxxx	14	14	10	13	10	13
		2. Plan for using a minimum number of connectors and of different types of connectors between components	• simplifies dismantling and reassembly of components	xxx	6	6	6	6	6	6
		3. Avoid secondary finishes	• reduces potential deterioration of usefulness/ attractiveness for reuse	x	2	2	2	2	2	2
		4. Avoid toxic and hazardous materials	• reduces potential health risks that might otherwise discourage disassembly	x	2	2	2	2	2	2
	Durable design	5. Design durable components that can withstand repeated use and outlast generations of buildings	• reduces damage to components and thereby increases the amount suitable for reuse	xxx	18	18	18	18	18	18
		6. Provide adequate tolerances for repeated disassembly and reassembly	• facilitates dismantling and reassembly	x	6	6	6	6	6	6
	High generality	7. Use standard dimensions and modular design	• gives architectural flexibility in second life	xx	12	9	0	0	12	12
		8. Aim for small scale and lightweight components	• eases handling and transport • facilitates self-building and local reuse • gives architectural flexibility in second life	x	6	4	0	0	4	5
		9. Reduce the complexity of components, and plan for using common tools and equipment	• special tools may not be identified or available • facilitates self-building and local reuse • gives architectural flexibility in second life	x	6	6	0	0	6	5
	Flexible connections	10. Use reversible connections for subassemblies	• enables dismantling of subassemblies • enables quality-control of components before reuse	x	3	3	0	0	3	0
		11. Plan for using reversible connections between components	• enables dismantling and reassembly of components • reduces contamination of materials • reduces damage to components	xxxxx	15	15	15	15	15	15
		12. Allow for parallel disassembly of components	• simplifies dismantling, particularly when only some parts of a building are being removed	xx	6	0	0	0	0	0
	Information and access	13. Provide identification of material and component types	• facilitates the planning of dismantling and the dismantling process • simplifies the sorting and reuse process	x	12	0	0	0	0	0
		14. Identify and provide access to connection points	• facilitates the planning of dismantling and the dismantling process	x	12	6	6	6	6	6

Figure 2. The assessment scheme showing criteria, strategies, reasoning, assumed relative importance (within each criterion) and scores.

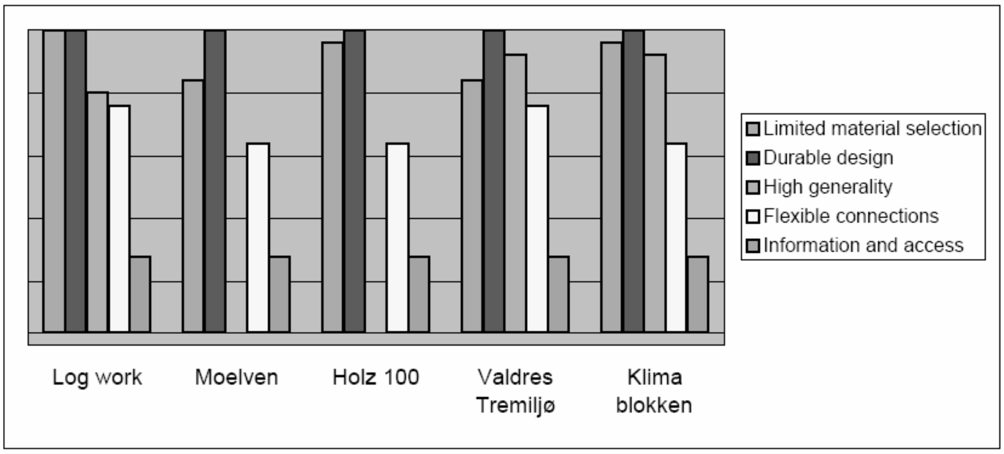

Figure 3. Scores for each criterion, shown as clustered columns.

3 DISCUSSION OF THE RESULTS

3.1 *Limited material selection*

A limited number of materials is desirable because it simplifies the dismantling and sorting process. Massive wood components are all basically made of wood, but the different connection methods for subassemblies make them different. The log is the only component that consists of wood throughout and that has no connectors, and it therefore receives full score. The other case objects have only one type of connector for the subassemblies; glue for the Moelven component, wooden pegs for the Holz 100 and Klimablokken components, and screws for the component of Valdres Tre. However, the nature of the connectors departs from the basic wood material to varying extents.

When it comes to the need for connectors between components (quantities and types), all the cases are assessed as moderate. Also, a full score is given for avoidance of secondary finishes and of toxic and hazardous materials, although these strategies are not considered highly relevant within this context.

3.2 *Durable design*

All the assessed components are considered to be durable. Although the wood quality may vary, this is not connected with the design of the construction components. High quality wood may last for centuries, even as external cladding if appropriately designed. Since also the tolerances are regarded as adequate, all case study objects receive full score for this criterion.

3.3 *High generality*

A high generality of building components will give architectural flexibility in a second service life, and this is crucial to increase the likelihood of reuse. Simple and common construction methods, standard dimensions and small to moderately sized components aim at giving freedom of design in a second service life, whereas too large and specialized components can only repeat the same building. The case objects of Moelven and Holz 100 belong to the latter category and demand crane equipment for construction as well as deconstruction. They therefore receive zero points for this criterion.

Vernacular log work is based on modules; the module being a quite imprecise log that requires adjustments for construction and for reuse. Because of this irregularity, traditional log construction does not receive full score for standardization. Industrialized versions of log construction, however, would have received a higher score for this criterion. The scale and weight of the log is assessed as moderate, and full score is given for low complexity and for being workable with common tools.

The Valdres Tre and Klimablokken components receive the best ratings for standard dimensions and modular design. They have both relatively low complexity, and scale and weight is low to moderate. This means that these components can be adapted for pre-fabrication in an industrial plant as well as for self-building. Also, the building can be constructed with common tools, something which is considered to facilitate local reuse. Within the criterion of generality, these two case-objects are therefore assessed to have the highest potential.

3.4 *Flexible connections*

Reversible connections between components are seen as a prerequisite for dismantling, and this strategy is therefore given the highest score within the criterion. All the components allow for reversible connections, although the component designs do not necessitate specific solutions. When it comes to reversible connections for subassemblies, only the components of Valdres Tre can offer this. Log construction also receives full score for this strategy because there are no subassemblies. However, this aspect is not seen as important for the objective of reuse.

None of the components allow for parallel disassembly.

3.5 *Information and access*

It is not common to label information about material and component type directly on wood components. One may claim that this is not necessary, because the wood material speaks for itself. Traditionally, logs were marked to identify where in the wall the component belonged, but this was not connected to material and component type. However, in a possible future where more focus is set on salvageable building materials in industrialized building, this line of action may be developed further. Here the field of product design can serve as a model for the building industry.

Although connection points are not identified, access is more or less evident in the constructions. This is true for all the components, and they therefore receive half score for this strategy.

3.6 *The assessment method*

In this study, we see that both the objective of the assessment (*reuse)* and the function of the case objects (*construction components*) are decisive factors for the weighting of the strategies. The reasoning given is also geared towards the objective of the assessment. If the objective was recycling instead of reuse, other strategies would have been stressed, e.g. *4; Avoid toxic and hazardous materials,* and *10; Use reversible connections for subassemblies*. Likewise, if the function of the case objects happened to be external cladding, e.g. strategy *3; avoid secondary finishes,* would have been considered more relevant than it is for constructions. In this way, the resulting weighting of each assessment will vary.

Furthermore, the criteria are considered to represent different aspects of reusability, and therefore they may also vary in mutual importance from one assessment to the other. More case-studies are needed to further investigate the usefulness of the method.

Besides examining the reusability of massive wood components, we wanted through this study to investigate the use of design guidelines as an assessment tool. The assessed parameters correspond directly with the strategies relevant for reusability of components, and they are expressed as specific design guidelines rather than performance standards. The method was therefore expected to give precision and transparency.

However, there may be a mismatch between the degree of accuracy of the scheme and the more approximate estimate of the qualitatively given scores. This suggests that an assessment method using performance standards at an intermediate level (Sassi 2002) may be just as relevant. On the other hand, this check list concept can be developed further through more case studies. We believe that it is important to retain the principle of traceability.

4 CONCLUSIONS

The results of the assessment show that the case objects differ from each other mainly on two criteria; *limited material selection* and *high generality*. Firstly, different types of connectors differentiate the wood components. Secondly, and most importantly, large differences are found for all the strategies within the criterion of high generality. The results indicate that there is a great potential to improve the reusability for the most commonly used Norwegian massive wood components. In a potential redesign, attention should be paid to the properties that give the components high generality and thereby architectural flexibility in a second service life.

If better reusability of the components was achieved, massive wood could become a first choice building material for closed loop buildings in a low carbon society. Small to medium scale modular components can be manufactured in industrial plants as well as locally by hand. The components should be workable with common tools because this is flexible and will facilitate self-building. In turn, self-building will address local reuse, which is the best environmental option.

When exploring the assessment method we see that transparency is achieved, but that there may be a mismatch between the degree of accuracy of the scheme and the more approximate estimate of the qualitatively given scores. More case-studies are needed to further investigate the usefulness of the method. However, we believe that the direct link between the guidelines and the assessed parameters is a step in the right direction.

To make reuse happen, there are obviously also other parameters than appropriate design that should be considered. Reuse was more commonly performed at earlier times because, among other factors, it was more cost-efficient to invest in work-hours than in material resources. It therefore became cheaper to reuse components than to buy new building material. Today it is the opposite trend, at least in the industrialized part of the world. However, environmental concern is slowly changing the legal and financial framework of the construction industry. Still, adapting the mindset and culture of decision makers is probably the hardest task.

Finally, the strategies for reuse should be seen as a source for architectural potential, not as a limitation. Durable and flexible material components aim at an environmentally justifiable lifetime, and a limited material selection facilitates the dismantling and sorting process. In addition, simplicity in the design may be regarded as an architectural quality: By restricting the material use and by keeping each component simple and clear, the buildings architecture may gain in refinement (Monsen 2006). The lesson is similar to what many architects teach: Keep it simple! Avoid overloads and fussiness, and cultivate each building material at its’ own premises.

REFERENCES

Berge, B. 2000. *Ecology of building materials*. Oxford Architectural Press.

Crowther, P. 2003. *Design for Disassembly*. Thesis, Queensland University of Technology.

Monsen, P. 2006. *Lecture*, NTNU

Nordby et al. 2006. Lifetime and demountability of building materials. Published in the *Proceedings of the Global Built Environment: Towards an Integrated Approach for Sustainability* (Editor M. Mourshed 2006, 8 pages) Available from http://www.ab.ntnu.no/bht/ansatte/nordby.html

Nordby et al. 2007a. Salvageability of building materials. *Paper submitted for SB07 conference in Lisbon: Sustainable construction, materials and practices.*

Sassi, P. 2002. Study of current building methods and products that enable dismantling and their classification according to their ability to be reused, recycled or downcycled. *International Conference for Sustainable Building*, Oslo

Motives for design for disassembly in building construction

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ABSTRACT: Design for disassembly, DfD (Design for Deconstruction), is an essential action to reduce the use of energy and resources and the production of waste in building construction. DfD has many environmental, economical as well as social benefits. It seams obvious to include the aspects of DfD, in both on-site and off-site production. Some countries have observed the importance of DfD and taken action but in many countries this is still a disregarded issue. This paper presents an overview of motives for DfD in building construction. The aim is to encourage clients and all actors in the building process to improve the discussion on DfD. The overview is based on the result of a systematic analysis of related fields such as DfD in product design, energy and resource efficiency in buildings, building deconstruction and salvaging of construction waste.

1 INTRODUCTION

Design for Disassembly, DfD, is an important measure to achieve sustainable building. What is DfD and what are the motives? DfD can be defined as a method to design a building/product in such a way that it enables the disassembly of building/components and reuse/recycling of its parts/materials. DfD requires a new approach to design and will result in a building/component designed for all the stages of its life-cycle. DfD is an essential action to accomplish the goals to reduce the use of both of energy and resources as well as the production of waste. DfD can also be regarded as an implicit meaning of the word *reduce* in the slogan "reduce, reuse, recycle"..

Within product design, research in DfD has been carried on for more than 25 years and DfD is today a well integrated method in product design. Within building design, general ideas regarding the favour of DfD (or Design for Deconstruction) was presented already in the 1970th by the architect Christopher Alexander. It was later developed in the 1990th by for example architects such as Francis Duffy and Stuart Brand.

In the last years, many countries worldwide has been given a lot of attention to DfD. Authorities, special interest oragnisation and companies have produced guidelines for DfD in building construction. Research have been carried out, doctoral thesis have been written and some are under way. In the Neatherlands, the Ministry of Housing, Spatial Planning and the Environment (VROM) implemented a project called Industrial, Flexible and Demountable, IFD, in which a great amount of demountable buildings have been built. Many developers and housing corporations in Holland have recently started to integrate DfD aspects in their development (Durmisevic 2007). In for example Australia, Canada and Great Brittan, an analysis of the building code regarding environmental issues was commissioned by the government. Several bodies for considerations pointed at DfD as an important matter to notice and develop.

There are many motives, both environmental, economical and social, for DfD in building construction and in the sections below is given an overview of motives and benefits. The motives can be summarised in

Economical motives
- Increased costs for waste handling
- Increased costs for extraction of resouce
- Increased score in environmental labelling for demountable buildings
- Increased terminal value for demountable buildings

Social motives
- Demeographic changes and changes in household structure
- Buildings are demolished before intended time

Enviromental motives
- Increased problems with waste production
- Lack of virgin resources
- Recycling and the quality of the end products
- Reduced need of energy need for building operation
- Climate changes

2 ECONOMICAL MOTIVES

2.1 *Increased costs of waste handling and resources*

Both waste and resources are connected with great costs in building construction. Economic instruments for environmental purposes are used in most European countries and are increasing. By 1994, the number of instruments had increased by over 50 % compared to 1987 [Hamilton 2001] and waste and resources are affected fields. In the 1990th, many countries introduced tax on waste, e.g. Denmark, Sweden, Holland, Finland, UK, and Germany [EFR]. Denmark introduced waste tax already in 1987, it has been increased continuesly and in 2001 it was tendoubled compared to 1987. Many countries have also tax on virgin materials. Tax on gravel was e.g. introduced in Sweden 1995, Denmark 1998, France 1999, and UK 2002 [EFR].

Easier disassembly would facilitate recycling, reduce waste and save resources.

2.2 *Environmental assessment of buildings*

Environmental rating is a widespread measure to promote the production of environmental products in general and there is a large number of environmental rating systems for buildings. The construction company Skanska considers environment rating as a necessary complement to legislation as it provides help to customers and lets the market work [Skanska 2007]. Environmental rating is also used by many construction companies and developers to market building projects, e.g Skanska and Brittish Colombia Construction Association, BCCA [Skanska, BRCCA 2007].

Consumers also consider envronmental rating systems as useful and in a survey, 32 % of the consumers answered that they certanly would pay 5 % more for an environmentally produced product and 48 % that they would consider to do so [Swedish EPA 2006].

In recent years, a few rating systems have included DfD-aspects, e.g. HK-BEAM, GreenGlobe and GBTool, and other systems are discussing the possibilities to include both DfD-parameters and recycling potential, e.g. EcoEffect [Glaumann 2007]. DfD is closely connected with the recycling potential and both are important parts of the environmental assessment of buildings. The goal is to develop a protocol that fairly allocates the loads, while at the same time encouraging planning and design decisions that facilitate greater recycling potential at the end of the use period [IEA 2001].

Buildings designed for disassembly and reuse/recycling will get higher score in environmental rating and the buildings' retail value will increase.

2.3 *Increased terminal value*

On a free market, the value of a building is decided by access and demand and a building's location is an important factor. Closure of a company, important for the employment in the region may suddenly change the demand for residential buildings in the region. Buildings which are easy to disassemble, move and rebuild in another location is likely to have a much higher terminal value than buildings which are not possible to disassemble.

3 SOCIAL MOTIVES

3.1 *Demographic changes and changes in household structure*

There is a general trend in developed countries towards an increase in one person households and based on scenarios this trend will continue [Alders 1999].

In Sweden, the share of one person households increased from about 30 % in 1975 to 46 % in 1990 [SCBa]. Besides changes in household composition, there will also be changes in regional population. The population in some counties is assumed to increase about 30 % while in other counties the population is assumed to decrease about 30 % [Samplan 1999].

3.2 *Buildings are demolished before intended lifetime*

There is a clear tendency through out the world that buildings are demolished before the intended lifetime. In Sweden, 25 % of the buildings which were demolished after 1980, were less than 30 years old [SCBb]. In Japan, the etimated lifetime for wooden residential buildings is 25-30 years and many buildings are demolished after only fifteen years (Nakajima 2001]. In a on commercial and residential buildings in St. Paul , Minnesota, demolished from 2000 to mid-2003, 30% were all less than 50 years old and 6% in less than 25 years old [Trusty 2005].

These figures support the view that we should do more to develop flexible and demountable buildings.

4 ENVIRONMENTAL MOTIVES

4.1 *Waste*

Some of the problems associated with waste and landfill are loss of arable land, loss of amenity value of the land, methane emission (a very potent greenhouse gas), leachate problems (liquids containing materials from landfill).

Construction and demolition waste in Europe makes up for approximately 25% of all waste generated in the EU [WasteBase 2007]. Denmark has well developed waste statistics and in Denmark the construction and demolition waste makes up for about 1/3 of all waste [EPA 2005]. Based on the amount of Swedish construction and demolition waste released 1996 and the recycling rates 1996, the net recycling potential was estimated. In terms of energy, the recycling potential could be increased at least 20-40 % [Thormark 2001]. However, as the demolished buildings were not designed for disassembly, the disassembly would be extremely costly to implement. In addition, the quality of the recycled end products would not be as high as it would have been if the buildings were designed for disassembly and recycling.

4.2 *Lack of virgin resources*

How long the earth's resources will last in general, is an uncertain issue. Nevertheless, with decreasing access to easily extractable resources, more energy will be needed to extract new resources.

In addition, for some specific resources essential for building construction, fairly reliable data is available. Geological Survey of Sweden has estimated that many Swedish municipalities, the supply of natural gravel will run out in less than 20 years if the extraction rate isn't drastically decreased [GSS].

4.3 *Recycling and the quality of the end product*

The cleaner and more homogeneous the waste fraction is, the more economical and environmental efficient is the recycling process. Sorting plastics for example, is a prerequisite to obtain high quality of the end product.

4.4 *Reduced energy need for building operation*

With decreased energy need for operation of buildings, the energy need for the material part (production, transports, maintenance) will make up for an increasing part of the total energy need during a building's life time. In Swedish low energy houses, the material part accounts for about 60-75 % of the total impacts during a service life of 50 years [Thormark 2007].

An important next step to reduce the total energy need is therefore to take notice of materials and joinings in order to produce reusable/recyclable constructions.

4.5 *Climate changes*

Due to climate changes, there is an increased risk of flood in Europe. More than 10 million people live in the areas at risk of extreme floods along the Rhine [Commission 2006) In Sweden, a survey has been performed regarding risk areas and several areas in risk for flood or landslide has been identified [SGI 2006].

Some areas the risks are obvious, however, in some areas there is a possible risk. In the case when it is difficult to tell *if* flood or landslide will occur, then it is even more difficult to tell *when*. In those areas, if very attractive for building, it would be possible to build demountable buildings which can be removed if the risks in the future show to be obvious.

Due to climate changes, new demands on buildings can be assumed, e.g. improved shading devices, improved ventilation, insect screens due to increase in mosquitoes etc. [Steemers 2003]. Steemers has also suggested that attention to an 'adaptive capacity' would be valuable in the design of buildings.

5 CLONCLUSION

Design for Disassembly, DfD, is an important measure to achieve sustainable building and requires a new approach in the design of buildings and building components. The motives for DfD as well as the benefits from DfD are of both environmental, economical and social kind.

REFERENCES

Alders, M.P.C. et al (1999). *Household Scenarios for the European Union*, 1995-2025. Statistics Netherlands.

BCCA, Brittish Colombia Construction Association, www.docksidegreen.ca

Commission of the European communities. (2006). *Proposal for directive of the European Parliament and of the council*. SEC(2006) 66. Brussel.

Durmisevic, E. PhD, Delft University. Personal communication, March 2007.

EFR, Ecological Fiscal Reform, Environment Canada. http://www.fiscallygreen.ca

EPA. (2005). *Affaldsstatistik 2005*. (Waste statistics), Environmental Protection Agency, Danmark.

Glaumann, M. PhD, Royal Institute of Technology, Stockholm. Personal communication, April 2007.

Hamilton, C. et al. (2001). *Taxation and the environment*. Paper Nr 44. The Australia Institute.

HK BEAM, An environmental assessment for new buildings, Version 4/04. HK-BEAM Society, Hong Kong.

IEA. (2001). LCA methods for buildings. Energy-Related Environmental Impacts of Buildings. Annex 31.

Nakajima, S., Futaki, M. (2001). National R&D Project to Promote Recycle and Reuse of Timber Constructions in Japan. *Proceedings of the CIB Task Group 39 – Deconstruction Meeting*, 9 April 2002, Karlsruhe, Germany.

SAMPLAN. (1999). *Slutrapportering av regeringsuppdrag om inriktningen av infrastruktur-planeringen för perioden 2002–2011*. Rapport 1999:2.

SCB a), Statistics Sweden. Number of households and type of households, (Antal hushåll efter hushållstyp FoB 75 - FoB 90).

SCB b), Statistics Sweden. Ombyggnad och rivning av flerbostadshus.

Skanska. (2007). environmental manager Johan Gerklev. http://www.skanska.se/skanska_site/templates/UtvaltProjekt____1551.aspx

Steemers, K. (2003). Towards a research agenda for adapting to climate change. International Journalf of BUILDING RESEARCH & INFORMATION (2003) 31(3–4), 291–301.

Swedish EPA. Swedish Environmental Protection Agency. (2006). Allmänhetens syn på företagens klimatarbete, märkningar och klimatmål. Report ARS P0793, Swedish EPA;

Stockholm.
SGI, Swedish Geotechnical Institute. (2006). På säker grund för hållbar utveckling. Uppdrag enligt regleringsbrev M2004/4162/A.
Thormark, C. (2001). Conservation of energy and natural resources by recycling building waste. *International Journal of Conservation, Resources and Recycling,* Vol 33/2, pp 113-130.
Thormark, C. (2007). Energy and resources, material choice and recycling potential in low energy buildings. CIB conference SB07 Sustainable - Construction, Materials and Practices. Lisbon, Portugal 12-14 September 2007.
Trusty, W.B., Argeles, C. (2005) An Empirical Perspective on Building Durability, 'An Empirical Perspective on Building Durability' The 10th Canadian Conference on Building Science and Technology, Ottawa, May 2005.
WasteBase. (2007). European Topic Centre on Resource and Waste Management Topic Centre of European Environment Agency.

Bionic breathing skin for buildings

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ABSTRACT: A breathing skin for buildings based on principles and methods abstracted from nature is presented. The skin reacts to changing conditions and influences the air pressure on the surface to perform a process of inhaling and exhaling. The system is created by a specific arrangement of a basic component, to utilize the space and the materials in an efficient way. The orientation and the geometry of the components allow deformations. These deformations are important to create a gradient pressure on the surface of the building skin, which results in sucking and expelling the air, which results in regulating the interior microclimates. Piezoelectric wires are used to generate the deformations. The rate of air-exchange is affected by the velocity of the component changing shape (deformation velocity). By developing this system we are not dealing with a separate ventilation system, but with an integral part of the building envelope which functions as a protective layer too.

1 INTRODUCTION

Buildings tend to stay static and monumental, while living organisms are adapted to their environment through evolution, and can respond to the changing conditions in their environment in the short term. For millions of years have nature been revolting and creating structures that tend to perfection in terms of energy consumption, environmental adjustment and survival. In "On Growth and Form", D'Arcy Thompson (1961) suggested that living things adapt their shapes to the physical forces applied on them. When a new structure is "born", a number of elements of the same environment participate for a certain period of time in its creation, either directly or indirectly. This environment can be influenced from other environments. Hence, every new structure (that survives) is born after a long and complicated procedure where many elements have contributed each in its own way and magnitude to build the features, characteristics and mechanism of the structure where beauty was not forgotten.

Biomimetics is not about nature imitation, but the observation at their properties and principles, and the transformation and the development of these principles into sophisticated technological solutions. These transformations can result in new means by which buildings can respond, adapt and interact to regulate their interior environment for the satisfactory of their users.

Several architects are inspired by nature, where forms and systems have specific functions, and are adaptive to environmental changes. For example, Antoni Gaudi was influenced by forms of nature among other inspiration sources. He designed a ventilation system for "Casa Batlló" by creating gradient pressure and thermo ventilation (Guardiola & Puente 2005). The Olympic Stadium, designed by Frei Otto, in Munich, Germany (Nerdinger 2005), where the form of the spider net provided an intelligent model maximizing the efficiency for the design. Frank Gehry (Aldersey-Williams 2003) and Greg Lynn (Rosa 2003) investigated and designed organic forms by using advanced computer technologies. Yet, the scale of their designs is not adaptive to environmental changes, and does not function like an organism. It seems that they are seeking for a form more than a function. Foster and Partners had designed a ventilation system for the "Swiss Re Headquarters" in London, which functions in the same way that sponges feed; they suck in water through basal membranes and drive it out through a chimney at the top (Aldersey-Williams 2003). The Emergence and Design Group directed by M. Weinstock, M. Hensel and A. Menges collaborated with researchers from the field of Biomimetics, where they provided models inspired from nature that can serve different functions for design (Hensel et al. 2004).

1.1 *Problem definition*

Building envelope is the medium between the outside (nature) and the interior spaces occupied by people, it is considered as a skin that provides thermal shell, one of its functions is ventilation. In the last decades, systems for buildings that respond to environmental changes have made rapid advances. Yet, they are controlled by computers and people, and function as a collection of devices that are added on the envelope such as louvers and shades. As a result, envelopes are complex and difficult to maintain and control. Sometimes solutions are forced for a specific environment; the natural dynamics are not utilized for the certain technical solution.

Smart and advanced materials are applied in architecture, but we cannot say that the building is advanced too. There are some separate local reactions and behaviors in the building, but they don't produce a global behavior. There is no clear hierarchy in geometry or materials adapted to buildings, which is essential for creating a global behavior.

2 APPROACH AND METHODOLOGY

In our research we develop adaptive systems to changing environmental conditions and integrate them into structures. The envelopes of such structures should have geometry and efficient techniques to respond to the environmental changes. To design such envelopes we rely on two main factors: developments in material technologies and natural systems.

The first factor has a great potential in architectural development. Some advanced materials can be applied to systems in structures and buildings to adapt their properties and hence optimize their performance. In this paper we, specifically, address the piezoelectric materials to be integrated in the envelope as will be further discussed in section 2.1.

The second factor presents an *infinite* source for research and knowledge that has been used by many researchers of different fields for different aims. Living organisms have unique integration geometries and techniques that allow them to adapt to different environments. Their development through evolution can take decades and centuries to give structural solutions (such as ventilating systems).

One of the challenges is the design of effective and efficient envelopes that uses the natural dynamics in the neighborhood of structures instead of counteracting with them. By investigating and studying different natural systems we were able to analogously apply solutions abstracted from nature in the desired system. This is discussed more in details in section 2.2. In the current work we pay a special attention on breathing organisms and circulation systems, and integrate the abstracted methods together with the piezoelectric material in the presented envelope.

2.1 *Piezoelectric materials*

Piezoelectric materials have the ability of converting mechanical energy into electrical energy and vice-versa. The phenomenon of piezoelectric was first observed by the brothers Curie in 1880. They realized that applying a pressure to a polarized crystal, results in an electrical charge due to the mechanical deformation caused by the pressure. Other materials, such as developed polymers, ceramics, and many natural crystals pose this property too.

The basic principle of piezoelectric effect is that the deformation in a piezoelectric material caused by a force results in changing the orientation of the dipoles at the surface. The piezoelectric effect also works in reverse. Applying a voltage at the dipoles results in polarized molecules; those align themselves with the electric field and a deformation in the material is produced. Piezoelectric materials can serve both as sensors and actuators (e.g. in skis to reduce vibrations under certain conditions; in valves to control movement of parts; and in speakers).

In our work we used piezoelectric wires for expansions and contractions of surfaces as will be discussed later on in the paper.

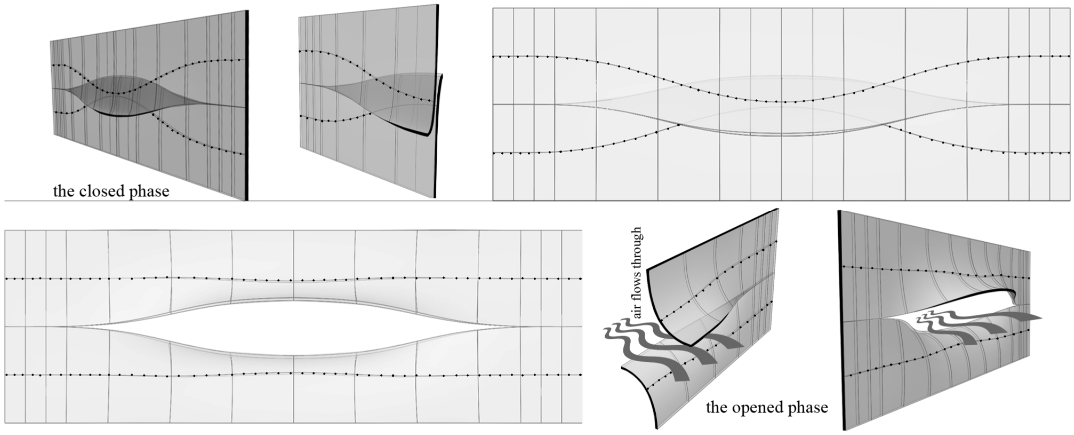


Figure 1. A possible application for the deformation caused by a voltage to a piezoelectric material

2.2 *Natural systems*

Natural systems are unique and various. They can sense and react to local changes causing a global behavior. Investigating and analyzing natural systems can result in models for dynamic and adapting materials. Size and proportion is important in such systems and should be considered prior to abstracting principles. In our analyses of natural systems we give special attention to ventilation systems (air exchange), which can be found in many living creatures for different tasks. The following cases from nature are brought to show different methods for ventilation and integration patterns.

(1) *Ascoinoide sponge*: It has an interesting geometric regularity that provides a unique circulation of water through and around its walls. The sponge consists of membranes on the envelope which sucks the food through them, and expels the water out through an atrium in the middle. The outer layer consists of thin cells which are tightly packed together. The inner layer consists of internal chambers, which are surrounded by a membrane that makes beat movements to create an active pumping process of water throughout the sponge walls and to absorb nutrients.

(2) *Respiration systems*: many living organisms have a mechanism in their body for exchanging air (inhaling and exhaling). There are four main respiration systems; (a) integument – where the exchange of gas occurs in the water directly through their integument; (b) gills – external tissues with many enfolding that increases the surface area for gas exchange. Organisms which live in water have this type of system for gas exchange; (c) lungs – the system is located inside the body connected to the outside by a pathway. By moving the muscles of the chest the air is sucked inside through the pathway to fill the lung. The lung has a great surface area of gas exchange due to its tiny protrusions inside; and (d) tracheae – the system is divided into a lot of small tubes that are in contact with muscles and organs. This kind of system functions in bodies less than 5 cm in length. Body movements increase the diffusion of gases inside.

(3) *The skeleton of a sea sponge*: the fibers of the skeleton are overlapped or overlaid in a regular or crisscross pattern, with diagonal fibers to reinforce the skeleton. When increasing the diameter of the sponge skeleton a spiral pattern is emerged to be stronger. According to Reichmanis (2005) the sponges are formed in a perfect way with the exact amount of material for optimizing the design. Understanding how their structures evolve could help in design processes.

(4) *The surface of a sea sponge*: sponges have an extraordinary surface features. They don't have organs, muscles or nervous system. They only have specialized cells for different purposes. The sponge can increase its volume and by that it increases the inner and outer surface area. It generates a water flow by a nonstop beat and movements of flagella (a long slender projection

from the cell body) which is part of the choanocytes (collar cells in the sponge). The water flows into the shafts through the pores in the body wall. The sponge also consist of oscules (outgoing of the channel system permeating the sponge) that close and open.

2.3 *Principles abstraction*

From studying and analyzing natural systems (presented in section 2.2) that perform ventilation or circulation processes, we abstracted the principles and methods that these systems are based on. And we summarized the main keywords in a table (Table 1) as a reference for our work.

Different methods for ventilation (gas exchange) are used in: the living organism itself and the living environment of the organism. We can recognize similarity between the method's principles in the two environments. In the case of the living organism itself we can see that the gas exchange is performed through a series of actions which is related mainly to parts movements influencing the air pressure to create a flow against the exchange tissues. The surface area of the exchange is greatly expanded in such natural systems, by dividing the system into many small parts, chambers or sub-branches. The gas exchange process in the two kinds of environments is happening continuously, and it depends on the pressure changes. Integration patterns are based on simple basic geometry to create more complex functionality of the system.

In our work we will refer to the following methods:

1. Generating gradient pressure by parts movements.
2. Increasing and decreasing the volume to result in sucking and expelling.
3. Dividing the system based on hierarchy.
4. Controlling the air-exchange by designing the surface pattern (sea sponge).

Table 1. a summary of keywords abstracted from the natural systems above(*2.2 natural systems*).

System	Keywords
Ascoinoide sponge	Circulation, membranes, sucking, expelling, atrium, cells, chambers, pumping, absorption.
Respiration systems*	Gas exchange, tissues, enfolding, surface area, pathway, muscles, sucking, protrusions, division, tubes, movements, diffusion, expansion, contraction.
The skeleton of a sea sponge	Helix like structure, overlapping, overlaying, crisscross pattern, diagonal, fibers, skeleton, increasing/decreasing, optimization.
The surface of a sea sponge	Differentiation, nonstop beating, movements, shafts, pores, close/open, channel system, permeable.

* lungs, gills, tracheae, integument.

3 PRINCIPLES TRANSFORMATION INTO ARCHITECTURAL SOLUTIONS FOR SKINS

Based on the principles and methods abstracted from the natural systems, a breathing skin for buildings was designed (Figure 2). We developed a skin that reacts to changing conditions and influences the air pressure on the surface to perform a process of inhaling and exhaling. It provides an extended surface area for air exchange created by a lot of small active units (a basic component). Increasing the exchange surface of the skin improves the ventilation through it. By this transformation we consider the envelope of the building as a ventilation system that improves the functionality of the building skin.

The designed skin is a system where local changes occur to create global behavior. The system is created by a specific arrangement of a basic component, to utilize the space and the materials in an efficient way. The orientation and the geometry of the components allow deformations in order to perform the inhaling and exhaling process which results in regulating the interior microclimates.

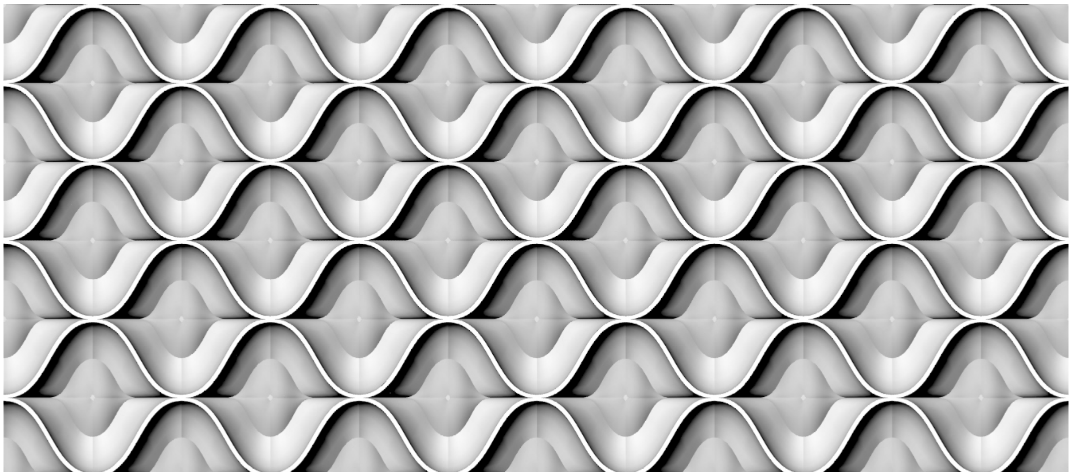


Figure 2. A computer generated view at the breathing skin 1:1.

3.1 *Basic component*

The component presented in Figure 3 is produced from elastic membrane that allows it to be flexible. The component cross section consists of three hierarchical parts: opened, semi permeable chamber, and a closed part. This hierarchy is important to create three chambers with different air pressure. The changes in the geometrical state of the components allow the air to flow in and out. The rate of air-exchange depends on the velocity rate of the component changing shape (deformation). Sensors are attached to the inner side of the skin, which give signals (through a control system) to the component to increase or decrease the deformation velocity. The middle chamber allows the air to flow in one direction. Hence it functions as a lung allowing air to flow in both directions (in and out). A more detailed explanation of this lung like chamber is discussed later in the paper.

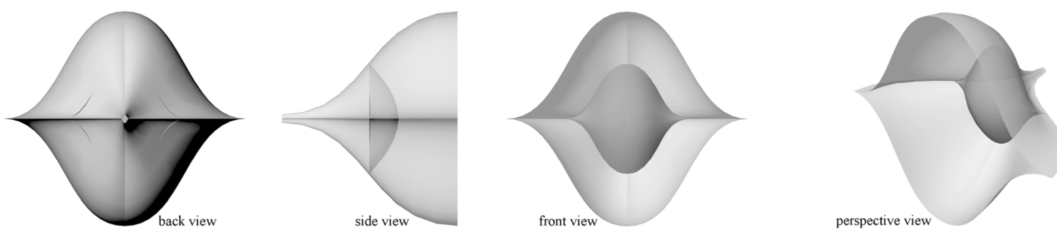


Figure 3. The active basic component.

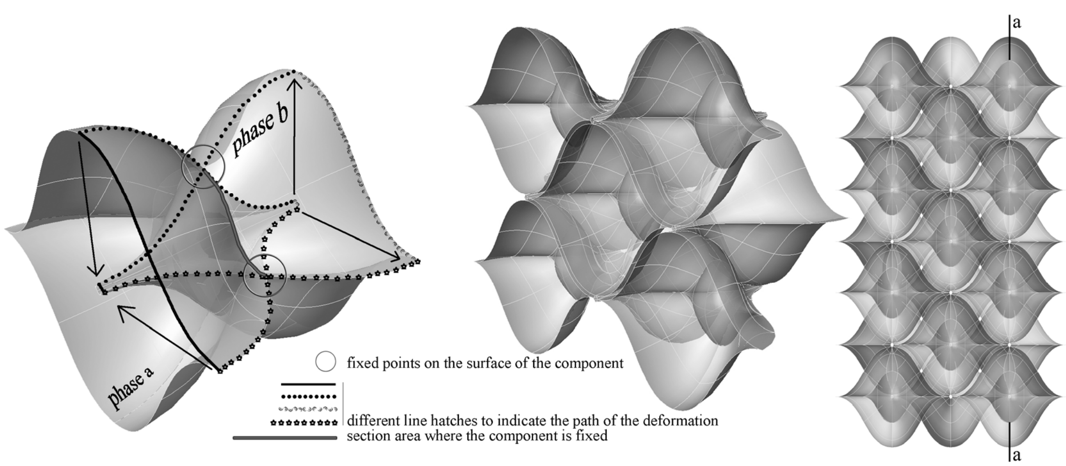


Figure 4. Component deformation.

3.2 *Basic component deformation and integration*

The deformation of the basic component is continuous. It deforms from phase a. to phase b. and vice versa (as shown in Figure 4, left). At phase a. the component is opened to the outside and closed to the inside, but this state is changing all the time at different velocities depending on the conditions of the interior space. The system is an integral part of the building envelope. The active ventilating components with their arrangement and geometrical integration create the protective envelope for the building, not just a protective layer but also an adaptive system based on bionic principles. The arrangement of the components creates an envelope that has the ability to perform dynamic continuous changes. Dynamics are produced due to geometry and material hierarchies. These dynamics generate gradient air pressure which in turn creates process of inhaling and exhaling, performed at the same time. While some components are performing inhaling other components are performing exhaling.

The components are made from membrane materials that are able to receive signals from sensors and respond by changing their geometry, this change will enable the air to permeate the lung like chamber from one side and expel it from the other side during the geometry change of the component.

3.3 *Lung like chambers arrangement in the system*

The position of the lung like chambers is fixed in the basic component. As mentioned earlier in Figure 4, there are fixed points in the basic component during their continuous changing. The chambers are based in the middle of the basic component cross-section, where the basic component is fixed and no movements occur. They are arranged in a diagonal crisscross pattern (as presented in Figure 5) to optimize the stability of the system. This net is the basic support of the dynamic system, where the basic component is attached to this net too. The two different color scales of lungs in Figure 5 imply the direction of air flow through the system. The air flows from outside to inside or from inside to outside through the lung and it doesn’t flow in reverse direction through the same lung like chamber.

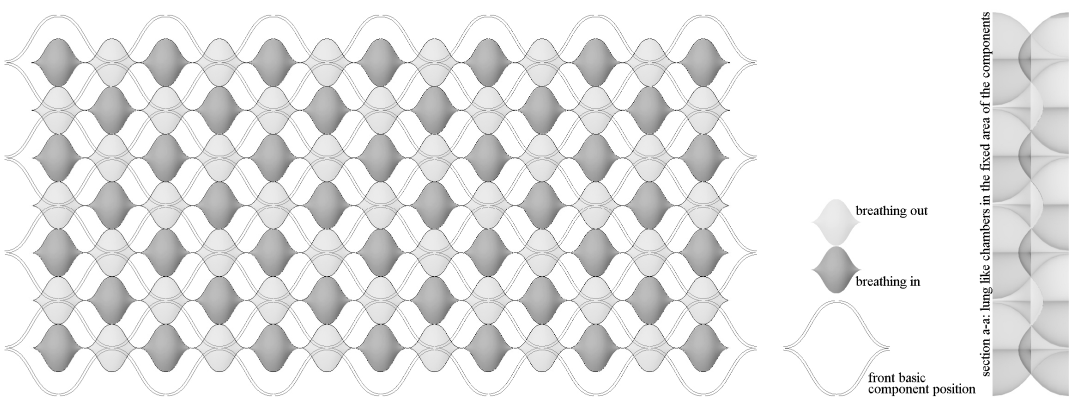


Figure 5. The pattern of the lung like chambers net.

3.4 *Piezoelectric material application*

The lung like chamber is designed on base of principles and methods abstracted from respiration systems, surface of the sea sponge and the asconoid sponge, which were presented earlier in section 2.2.

The lung like chamber consists of two surfaces attached to each other at their edges creating a specific volume in the basic component (as presented in Figure 6a). Piezoelectric wires are attached on the surfaces of the lung like chamber. Each surface is controlled separately (Figure 6c & 6d). When a voltage is applied to the piezoelectric wires on one of the surfaces, the lung expands and increases its volume and by that it increases the inner and outer surface area. A low pressure is created in the lung which results in sucking the air inside the lung (Figure 6c). The air flows into the lung through shafts on the surface of the lung. The shafts are designed in a way that allows the air to flow in one direction; valves are attached to the inner surface to the shafts, when the air pushes on the inner surface towards out, the valves are contracted and closed. Stopping the voltage from the surface results in contraction and creating over pressure. A voltage is applied to other side of the lung (Figure 6d), which expands it and allows the air to flow out through the shafts to the other side.

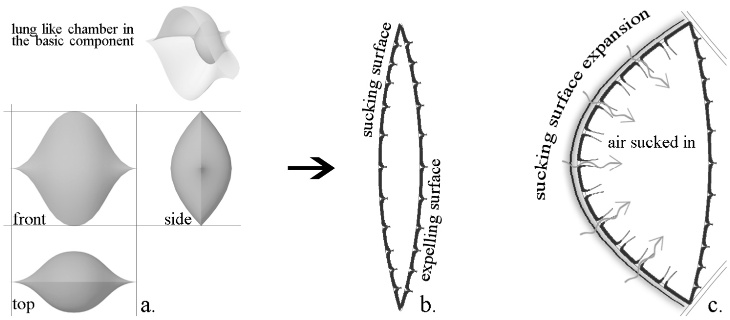


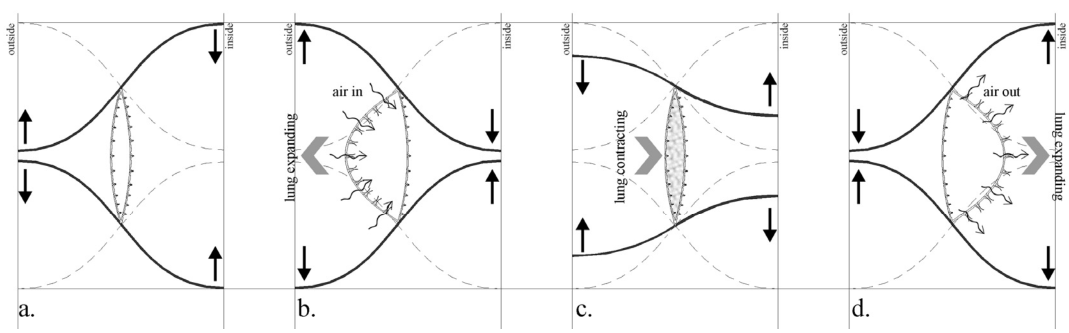
Figure 6. The expansion of the lung like chamber.

3.5 *Lung expansion and contraction combined with basic component deformation*

In natural respiration systems air circulation is generated by a nonstop beat or movements of the muscles or different parts of the system. These movements create over/low pressure where the air is sucked or expelled, as already explained before and summarized in section 2.3.

Based on section 2.3, the expansion and contraction of the lung is combined with the movements of the basic component. When a voltage is applied to piezoelectric wires on the lung, results in the expansion of the lung, and at the same time the basic component deforms and opens to create a bigger volume on that side where the lung had expanded. Creating a bigger volume increases the low pressure and increases the air sucking from the surrounding environment. Stopping the voltage will result in contracting the lung and creating over pressure inside, at the same time; the basic component is deforming and closing the side where the air was sucked inside the lung, and opening with creating a bigger volume at the other side where the voltage is applied on the lung at that side. Creating the bigger volume in the basic component creates low pressure which will result in improving the air expelling from the lung to the other side, And so on. In this way the skin sucks air from one side and expels it to the other side. The skin consists of lung-like chambers that take air from outside to inside, and of lungs that take air from inside to outside. In this way the air is exchanged continuously.

Figure 7. (a.)-(d.) describes the process of air exchange that occurs in the new skin.



4 CONCLUSIONS

We had developed a skin that performs a gas exchange process which can be integrated into structures with the property of adaptation to changing environmental conditions, based on principles abstracted from natural organisms. The developed skin has a unique geometry and integrity, which allows it to react to the environmental changes. The elastic material used for the skin is important to make it possible to react and change continuously. Utilizing advanced materials in the design, which are not common in the building industry, opens new opportunities for better solutions for building envelopes. By developing this system we are not dealing with a separate ventilation system, but with a system that is an integral part of the building envelope which functions as a protective layer too.

Currently we are running simulation tests to investigate the behavior of the ventilating system for structures with different requirements in order to optimize their functionality. We also intend to test a prototype of the developed system based on the required improvements (from the simulations). Our vision includes a new class of building envelopes which are self-adapting systems that can behave "intelligently". This class is a result of ideas transformed from nature, with the property of adaptation to changing environmental conditions.

REFERENCES

Addington, M. and Schodk, D. 2005. *Smart Materials and Technologies*. Oxford: Elsevier-Architectural Press.

Aldersey-Williams, H. 2003. *Zoomorphic: New Animal Architecture*: 42-49 and 98-99. London: Laurence King Publishing.

Hensel, M., Menges, A. and Weinstock, M. 2004. Emergence: Morphogenetic Design Strategies. *Architectural Design* Vol 74 No 3. London: Wiley-Academy.

IL 6, 1973. *BIOLOGY AND BUILDING 3*. Institute for Lightweight Structures, Stuttgart.

Nerdinger, W. 2005. *Frei Otto Complete Works: Lightweight Construction Natural Design*. Basel: Birkhauser publishers.

Purves, W. and Orians, G. 1983. *LIFE: The Science of Biology*. Boston: Willard Grant press.

Reichmanis, E. 2005. *Research on Deep-Sea Sponge Yields Substanial Mechanical Engineering Insights*.

Rosa, J. 2003. *Next Generation Architecture*: 137-139. New York: Rizzoli International Publications.

Teuffel, P. 2006. Utilization of Advances in Material and Computer Science for Building Structures, *Game Set and Match II*: 264-270.

Thompson, D'Arcy Wentworth 1961. *On Growth and Form*. Cambridge University Press, Cambridge.

Tsui, E. 1999. *Evolutionary Architecture: Nature as a Basis for Design*. Toronto: John Wiley & Sons

Usón Guardiola, E. and Cunill de la Puente, E. 2005. Passive solar design in Antonio Gaudi's domestic architecture. Int. Conf.: *Passive and Low Energy Cooling for the Built Environment*, Santorini.

An ecosystem based biomimetic theory for a regenerative built environment

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ABSTRACT: Biomimicry, where flora, fauna or entire ecosystems are emulated as a basis for design, has attracted considerable interest in the fields of architectural design and engineering as an innovative new design approach and importantly as a potential way to shift the built environment to a more sustainable paradigm. The practical application of biomimicry as a design methodology, particularly in the built environment, remains elusive however. This paper seeks to contextualise the various approaches to biomimicry and provides an integrated set of principles that could form the basis for an ecosystem based design theory. This would enable practitioners to reach beyond sustainability to a regenerative design practice where the built environment becomes a vital component in the integration with and regeneration of natural ecosystems as the wider human habitat.

1 INTRODUCTION

Approaches to biomimicry as a design process typically fall into two categories: Defining a human design problem and looking to the ways other organisms or ecosystems solve this (design looking to biology), or identifying a particular characteristic in an organism or ecosystem and using it to provide a solution to a human problem (biology influencing design) (Biomimicry Guild, 2007). Within these two approaches, there are three levels of mimicry: Organism level, behaviour and ecosystem levels as detailed by Pedersen Zari (2007).

Through an examination of existing biomimetic technology and literature it is clear that markedly different approaches to biomimetic design have evolved and can have different outcomes in terms of an increase in overall sustainability. Examples of biomimicry are typically of products or materials, and tend to mimic a single organism. As Reap et al. (2005) demonstrate, products or materials that are organism biomimetic without also being ecosystem biomimetic are not inherently more sustainable when analysed from a life cycle perspective. An example given by Baumeister (2007) is Velcro. While Velcro mimics how burs of certain plants attach to animal fur, the product itself is made from petrochemicals and is not typically recycled or recyclable, nor does it take into account any of the other principles of ecosystems.

An ecosystem based approach to architectural design will be discussed in this paper, however the social, psychological and aesthetic implications of such an approach are not explored in this context. The potential relationships with biophilia, evolutionary psychology (Storey & Pedersen Zari, 2006) and integration or interface with non-human-dominated ecosystems are acknowledged with ecosystem based biomimicry. The possible links with Construction Ecology (Kibert et al., 2002) and Building Ecology (Graham, 2003) are also acknowledged.

2 ECOSYSTEM BASED BIOMIMICRY

Humans affect ecosystems and evolutionary processes at great rates and in multiple ways (Imhoff et al., 2004). Despite traditional approaches in the study of ecology where systems tended to be studied as unaffected and separate from human influence, it may be as Alberti et al, (2003) suggest, impossible to look at ecosystems as separate from human systems.

Despite the fact that there may not be any ecosystems that are truly unaffected by humans, and that humans are inherently part of the natural world, there are some obvious and essential differences in the way that non-human-dominated and human-dominated systems work. Non-human-dominated ecosystems, particularly those that are k-strategists (more complex and longer lived), tend to function in way that is conducive to dynamically sustained and ongoing life (Benyus, 1997, Berkebile and McLennan, 2004). In this particular period of human existence, there are perhaps some valuable observations humans can make of 'natural' ecosystems in the creation of human habitat that is able to integrate with and regenerate rather than damage the ecosystems they are part of.

3 BIOMIMICRY AND ARCHITECTURAL DESIGN

Biomimicry, particularly at the ecosystem level has yet to be meaningfully explored in built form, with few examples existing beyond an aesthetic metaphor. A documented example that does go beyond a simple mimicking of form is Mick Pearce's Eastgate Building in Harare, Zimbabwe and the CH2 project in Melbourne, Australia based on the mimicking of the building behaviour of certain termites. The temperature regulation observed in the mounds is achieved through careful orientation, spatial organisation and techniques of passive ventilation. Aldersey-Williams (2003) also details a number of buildings that mimic animals in various ways. Although most do not go beyond the form level, a notable exception is the Waterloo International Terminal. Designed by Nicholas Grimshaw & Partners, the terminal is able to respond to changes in air pressure as trains move through it. Its glass panel fixings mimic the flexible, scaly Pangolin making them able to move in response to imposed forces.

4 BIOMIMICRY FOR REGENERATIVE DESIGN

While biomimicry at the organism level may be inspirational for its potential to produce novel architectural designs, the possibility exists that a building as part of a larger system, that is able to mimic natural processes and can function like an ecosystem in its creation, use and eventual end of life, has the potential to contribute to a built environment that goes beyond sustainability and starts to become regenerative (Van der Ryn, 2005; Reed, 2006).

Although the authors are not aware of any built architectural examples that demonstrate comprehensive ecosystem based biomimicry, there are proposed projects that display aspects of such an approach such as the Lloyd Crossing Project proposed for Portland, Oregon. The project's design team including Mithūn Architects and GreenWorks Landscape Architecture Consultants use estimations of how the ecosystem that existed on the site before development functioned, termed by them *Pre–development Metrics*™ to set a wide range of goals for the ecological performance of the project over an extended time period.

5 ECOSYSTEM RESEARCH

Ecology literature typically does not offer sets of generalised principles but tends to explore the complexities of certain aspects of ecosystems. While there is considerable overlap in how ecosystems are described between sources, not all authors are in agreement. Because of the interconnected nature of ecosystems and the ways in which they function, it is difficult to organise generalised principles into a neat list which accurately encapsulates the complexity of the relationships between each principle (Charest, 2007). It is however considered that an examination of the relationships between each principle has potential to offer additional insights into how human design could be based on ecosystems and that the development of a comprehensive relationship diagram could be a useful step in the evolution of a model that is able to portray this. A recent iteration of the Biomimicry Guild's *Life's Principles* remains the only non-linear model of this type that the authors are aware of (Biomimicry Guild, 2007).

In this case, Pedersen Zari conducted a comparative analysis of related knowledge of ecosystem principles in the disciplines of ecology, biology, industrial ecology, ecological design and biomimicry and used this to formulate a group of ecosystem principles aiming to capture cross disciplinary understandings of ecosystem functioning. It is intended that this biomimetic theory in the form of a set of principles based on ecosystem function could be employed by designers, to aid in the evolution of methodologies to enable the creation of a more sustainable built environment.

An initial matrix (available from the authors upon request) was used to compare information from explanations of generalised ecosystem principles. From this, an inventory was complied encompassing as much of the information as possible. The following sources were used: Benyus (1997), Berkebile & McLennan (2004), Biomimicry Guild (2007), Copeman (2006), de Groot et al. (2002), Faludi (2005), Hastrich (2006), Hoeller (2006), Kelly (1994), Kibert et al. (2002), Korhonen (2001), McDonough & Braungart (2002), Reap et al. (2005), Thompson (1942), Vincent (2002), Vincent et al. (2006) and Vogel (1998). Additional sources, typically from the discipline of ecology were used to expand upon each principle.

6 ECOSYSTEM PRINCIPLES

The ecosystem principles provided here are proposed as a set of generalised norms for the way most ecosystems operate rather than absolute laws and should be taken as a starting point for further research to fully understand the different and important aspects of each simplified principle. Without comprehensive explanations of each principle, which is beyond the scope of the paper, the effectiveness of simplified lists of ecosystem principles aimed at use by designers with little background ecological knowledge are likely to remain at the level of metaphor. While Korhonen (2001) points out that mimicking at the metaphoric level is not insignificant in terms of increasing overall performance of the built environment, opportunities exist for design to be positively integrated with global biogeochemical cycles through a thorough understanding of ecology beyond the metaphoric level.

The principles provided in Table 1 should not be taken as a comprehensive explanation of the ways ecosystems function, but are intended to give designers with limited knowledge of ecology a set of operating principles which, if employed, could significantly improve the sustainability of the human built environment. A brief explanation of each principle follows Table 1.

Ecosystem principles listed can be applied to the design process by transforming them into a set of questions that are asked of the project at each stage of the design (Biomimicry Guild, 2007, Charest, 2007).

Table 1. Ecosystem Principles

1. Ecosystems are dependant on contemporary sunlight.
   - -Energy is sourced from contemporary sunlight.
   - -The sun acts as a spatial and time organising mechanism.
2. Ecosystems optimise the system rather than its components.
   - -Matter is cycled and energy is transformed effectively.
   - -Materials and energy are used for multiple functions.
   - -Form tends to be determined by function.
3. Ecosystems are attuned to and dependant on local conditions.
   - -Materials tend to be sourced and used locally.
   - -Local abundances become opportunities
4. Ecosystems are diverse in components, relationships and information.
   - -Diversity is related to resilience.
   - -Relationships are complex and operate in various hierarchies.
   - -Ecosystems are made up of interdependent cooperative and competitive relationships.
   - -Emergent effects tend to occur.

-Complex systems tend to be self organising and distributed.

5. Ecosystems create conditions favorable to sustained life.
   -Production and functioning is environmentally benign.
   -Ecosystems enhance the biosphere as they function.
6. Ecosystems adapt and evolve at different levels and at different rates.
   -Constant flux achieves a balance of non-equilibrium
   -Limits, tend to be creative mechanisms
   -Ecosystems have some ability to self heal

6.1 *Sunlight.*

Solar radiation is the only input into the closed loop ecosystem of earth and except for gravitational effects of the moon, is the only source of energy either directly or indirectly available to organisms. The majority of ecosystems exist through utilising contemporary sunlight (recently received from the sun) that has been converted by photosynthesis into biomass, which forms the basis of the food chain (Kibert et al., 2002). In contrast, humans currently source a large proportion of energy from ancient sunlight in the form of hydro carbon based fossil fuels.

Oxygen production, the hydrological cycle, wind currents, and drivers for certain ocean currents and other cycles are all caused by or are intimately linked with solar radiation (Xiong, 2002). As Baumeister (2007) points out, organisms tend to use 'free energy'. Examples are wind dispersed seed pods using air currents, or marine mammals exploiting water currents in migration. Ultimately this resourceful use of 'free' energy is also the harnessing of converted energy from the sun but by means other than directly through the food chain.

The sun also acts as a timing and directional orientation or spatial organisation mechanism. Biological rhythms such as diurnal and annual (or longer) cycles are determined by the sun's gravitational effect and the rotation of the earth. Migration patterns or flowering seasons in some species in response to these cycles are examples of the role the sun (or the earth's relative position to it) has in timing mechanisms in ecosystems. Many plants are able to sense the direction of the sun and therefore grow or move towards (or away) from it, enabling greater photosynthesis efficiency or other advantages (Benyus 1997). Wind and rain patterns, are also indirectly linked to solar radiation and are important organisational factors in ecosystems, determining where and in what formation organisms are able to inhabit a microclimate.

If the built environment was based on this one principle alone as is advocated by sustainable design theory in general, where it's energy was derived from contemporary sunlight and it was sited and organised according to climate, detrimental environmental impacts would be considerably less and there may be consequent significant positive physical and psychological health impacts (Kellert, 2005).

6.2 *System optimisation*

Ecosystems use energy and materials in a way that optimises the whole system rather than individual components (Kelly, 1994). What would appear to be inefficiency in individual organisms can sometimes equate to effectiveness for the entire system (McDonough & Braungart, 2002). Ecosystems tend to cycle matter in large closed loop systems, where the wastes of one organism become the nourishment of the next, through connected food webs at different scales. Detritus becomes a fundamental part of the health of the system (Odum, 1969).

Although matter can be cycled, energy will flow through a system (Korhonen, 2001). Benyus (1997) points out that *'the pyramid of life is quite literately an energy distribution chart, a record of the sun's movement through the system.'* Allen (2002) discusses the way that biological systems degrade energy in a large number of small steps, rather than in a small number of large steps, as tends to be the case in human systems and that these pathways of dissipation tend to be highly deliberate and important to the overall system. This allows energy that is left after one organism has done work to be utilised by another, so energy use is maximised.

In an example of both materials and energy effectiveness, organisms in ecosystems tend to use materials for more than one function (Benyus, 1997). This means less energy is expended and can be used for other functions such as health, growth and reproduction for example.

Reap et al. (2005) describe the characteristic of form fitting to function as *'the use of limited materials and metabolic energy to create only structures and execute only processes necessary for the functions required of an organism in a particular environment.'* Geometry and relative proportions found in nature are further offered as examples of materials and energy efficiency by various authors (Vogel, 1998, Faludi, 2005).

A built environment that mimicked this aspect of ecosystems through multifunctional use, closed loop functionality and overall system optimisation to ensure effective material cycles and careful energy flow would beneficially challenge conventional attitudes to building boundaries and the idea of waste.

6.3 *Local context.*

Species that make up ecosystems tend to be linked in various relationships with other organisms in close proximity (Allenby and Cooper, 1994, Korhonen, 2001). They typically utilise resources and local abundances from their immediate range of influence, and tend to be well adapted to their specific microclimatic conditions (Reap et al., 2005).

The Gaia hypothesis proposed by Lovelock posits that living communities may not be passively dependant on the local environment but may influence their microclimate as part of their initial adaptation to the environment (Harding, 2001). Both Gaian theory and the conventional ecology view that life adapts to local environment, point to ecosystems and the organisms in them seeming to be attuned to and suited to the climate and environment that they exist in.

The functions required for an ecosystem to continue and remain in dynamic balance, including the cycling and production of materials, are usually carried out by species within the system, existing in specific niches and linked with each other (Benyus, 1997). The ecosystem as a whole is able to be responsive to local conditions through extensive feedback loops created by the relationships between these organisms.

Incorporating this principle into the built environment implies that a thorough understanding of a particular place would be required of the design team and that local characteristics of ecology and culture would be seen as drivers and opportunities in the creation of place.

6.4 *Diversity*

A diverse system is often described in biomimicry literature as a robust and stable one capable of adapting to change. In certain levels of ecosystems and in individual organisms there may be a level of redundancy to allow for adaptation to changing conditions at different rates. Some ecologists describe this as the 'insurance effect' (Shear McCann, 2000). This concept is usually expanded upon in ecology literature, and it should be noted that there is considerable historical debate about the relationship between diversity, complexity, resilience and stability in ecosystems. What is clear from the literature is that the number and strength of relationships between species in systems is more important to dynamic stability than actual numbers of species (Shear McCann, 2000). Through this kind of cooperative networking, one element (or organism) can fail without disrupting the entire system.

Ecosystems are organised hierarchically (Kibert et al., 2002), and at different scales may be governed by different physics principles (Vogel, 1998, Thompson, 1942). In complex ecosystems both cooperation and competition between individuals and species are important in the creation of ecosystem dynamics (Kibert et al., 2002). Organisms will occupy non-competing niches and species in the same niche may use tactics such as defining territories or having non-overlapping feeding times to avoid competition. Reap et al. (2005) discusses life existing in a cooperative framework as relating to *'the diverse web of interactions that effect populations, facilitate resource transfers, ensure redundancy and generally maintain the biosphere.'*

Emergence in ecosystems is the phenomena of novel and unexpected organisation in complex systems. Allen (2002) asserts that it is through new relationships of control and constraint that emergence appears, allowing systems to become more complex. Ecosystems tend to be made up of distributed and decentralised networks of feedback loops dependant on relationships between organisms, and between the living system and the rest of the environment, making them rapidly responsive and adaptable to change (Vincent et al., 2006). Kibert et al. (2002) describe this aspect of ecosystems as *self-organisation*. This kind of organisation, based on multiple feedback mechanisms, tends to incorporate high amounts and transfer rates of information (Allenby and Cooper, 1994).

Translating this into the built environment implies a systems approach to architectural design where considering the facilitation of relationships between buildings or components is as important as designing the individual buildings themselves.

6.5 *Life enhancement.*

The growth and activities of organisms tend not to damage the ability of the overall system they are a part of to exist and continue (Benyus, 1997, Rosemond and Anderson, 2003). Organisms must manufacture or process the materials or chemicals they need in the same environment that they live in and concentrated toxins, such as snake venom for example tend to be produced and used and locally (Kibert et al., 2002). This is in direct contrast to the typical human approach towards manufacturing. Allenby & Cooper (1994) point out that chemicals including nutrients are toxic in natural systems if in high concentrations, and that living systems typically do not have clusters of high energy and materials transformations and that high fluxes in the use of energy and materials are avoided. Natural materials are all produced at ambient temperature and often use water as the chemical medium (Reap et al., 2005). Benyus (1997), contrasts this with the human tendency to produce materials in high energy, pressure and chemically intensive conditions; the *'heat beat and treat'* approach rather than allowing *'the physics of falling together and falling apart – the natural drive towards self – assembly'* to do the work.

Ecosystems may do more than avoid polluting and in fact may regenerate, and strengthen the system as organisms in it live and die. *'Life on Earth alters Earth to beget more life'* (Kelly, 1994). Rosemond & Anderson (2003) point out that classifying the effects of species in ecosystems as beneficial or detrimental is largely a subjective human interpretation, but may include facilitating the presence of other species and increasing nutrient cycling and mutually beneficial relationships. As ecosystems shift from development stages to more complex stages through time and through the combined activities and interactions of the organisms within them, the system tends to become more adaptable to change and is able to support more organic matter and organisms with longer and more complex life cycles (Odum, 1969, Faludi, 2005).

Mimicking this aspect of ecosystems would require the built environment to be considered as a producer of energy and resources and that it be designed to nurture increased biodiversity in the urban environment. An understanding of ecology in the creation of the built environment would form the basis of it being able to participate in the major planetary cycles (such as the hydrological and carbon cycle etc) in a way which reinforces and strengthens them rather than damages them.

6.6 A*daptation and evolution*

Adaptation and evolution allow organisms and whole ecosystems to persist through the locally unique and constantly dynamic, cyclic environment they exist in. Reap et al. (2005) describe adaptation as the means by which an organism adjusts (behaviourally and physically) to change throughout a lifetime. Evolution is referred to as the process by which genetic changes happen though successive generations in species or ecosystems through the medium of the gene.

Ecosystems are essentially in a constant state of flux and it is this very state of flux that keeps an ecosystem dynamically stable (Allen, 2002). Allenby & Cooper (1994) point out that *'mature communities* [are] *highly dynamic systems, and many subsystems will be in flux at any given time (for example, exhibiting spatial 'patch dynamics'). Maturity is not stasis'*.

Benyus (1997) touches on the idea that nature *'curbs excesses'* from within systems (internal feedback) as well as from external events or changes (external feedback). Feedback mechanisms, or the way that changes in one part of the ecosystem are communicated throughout the entire community are cited as a factor in the ability of ecosystems to adapt and evolve (Allenby and Cooper, 1994). Limits existing in ecosystems are also often discussed in terms of carrying capacity and intensity of flows of materials and energy (Berkebile & McLennan, 2004).

The implications of applying this principle to architectural design could range from a redefinition of when a building is considered to be finished, designing it to be more dynamic over time (applying techniques for additive and adaptable design and design for disassembly for example), to designing systems that incorporate some level of redundancy to allow for added complexity to evolve over time, increasing the ability of the built environment to be able to respond to new conditions and possibly to become self-maintaining.

7 CONCLUSIONS

Since the industrial revolution, esteemed examples of architecture have typically been based upon the metaphor of the machine of the industrial age as demonstrated by Le Corbusier's famous quote: *'The house is a machine for living in'*. Korten, (2007) discusses the importance of changing the metaphors, or 'stories' cultures are based on, while Gould & Hosey (2007) elaborate on the expansion of the conversations communities must have if humans are to become more sustainable. If ecosystems rather than machines are to become the philosophical design metaphor and the practical metric for architectural design, the built environment may come to be considered less as a collection of distinct buildings that behave like objects set in an arbitrary landscape, but rather as nodes in a system that become conduits, and ultimately producers of energy and nutrients (materials) in a complex, cyclic system. This is in contrast to the current status of the built environment as a heavy consumer and polluter. Such an approach is ultimately rooted in the design team having a deep and intimate understanding of the context of the place a design is sited in, as well as an understanding of basic ecology.

The importance of architectural design based on an understanding of ecology is discussed by researchers advocating a shift to regenerative design (Reed, 2006). This discourse tends to be theoretical at present and as such many of the ideas expressed in this paper have yet to be tested in realised built form.

Such an ecosystem based biomimicry is likely to be dependant on a collaborative approach to design that includes both design professionals and ecologists. Even with increased collaboration, achieving success in such an approach may be dependant on design professionals understanding basic concepts of ecology and ecologists understanding basic concepts of design. Only then perhaps will designs based on ecosystem principles transcend the level of metaphor and incorporate a 'deeper' form of biomimicry, able to imbue buildings with the ability to become a functioning part of ecosystems.

An ecosystem based biomimicry operating formatively in setting the initial goals and in establishing the performance standards by which the appropriateness of changes to the built environment are evaluated, has the potential to create a significantly more sustainable and ultimately regenerative built environment, transforming ideas about what the built environment is and how it relates in a mutualistic way with the ecosystems it is part of, particularly if humans collectively begin to behave like a species that intends to remain on earth.

REFERENCES:

Alberti, M., Marzluff, J. M., Shulenberger, E., Bradley, G., Ryan, C., & Zumbrunnen, C. (2003). Integrating humans into ecology. *BioScience, 53*(12), 1169-1179.

Aldersey-Williams, H. (2003). *Zoomorphic - new animal architecture*. London: Laurence King.

Allen, T. F. H. (2002). Applying the principles of ecological emergence to building design and construction. In C. J. Kibert, J. Sendzimir & G. B. Guy (Eds.), *Construction Ecology*. London: Spon Press.

Allenby, B. R., & Cooper, W. E. (1994). Understanding industrial ecology from a biological systems perspective. *Total Quality Environmental Management, Spring*, 343-354.

Baumeister, D. (2007). Presentation at the University of Washington, Seattle, WA. 8 May.

Benyus, J. (1997). *Biomimicry - innovation inspired by nature*. New York: Harper Collins Publishers.

Berkebile, B., & McLennan, J. (2004). The living building. Biomimicry in architecture, integrating technology with nature. *BioInspire 18*.

Biomimicry Guild (2007). *Innovation inspired by nature work book*: Biomimicry Guild.

Charest, S. (2007). Ecosystem principle research. Personal Communication, May.

Copeman, D. (2006). Permaculture for urban sustainability - draft chapter for the book steering sustainability: Royal Melbourne Institute of Technology.

de Groot, R., Wilson, M. A., & Boumans, R. M. J. (2002). A typology for the classification, description and valuation of ecosystem function, goods and services. *Ecological Economics, 41*, 393-408.

Faludi, J. (2005). Biomimicry for green design. *World Changing*.

Gould, K., & Hosey, L. (2007). *Women in green*. Bainbridge Island: Ecotone Publishing.

Graham, P. (2003). *Building ecology - first principles for a sustainable built environment*. Oxford: Blackwell Publishing.

Harding, S. (2001). *Complexity and stability in a Gaian ecosystem model.* Paper presented at the International School Earth and Planetary Sciences, Earth Science System, Siena.

Hastrich, C. (2006). The biomimicry design spiral. *Biomimicry Newsletter, 4*(1), 5 - 6.

Hoeller, N. (2006). Patterns in nature: Sustainability Innovation Network. Unpublished work.

Imhoff, M. L., Bounoua, L., Ricketts, T., Loucks, C., Harriss, R., & Lawrence, W. T. (2004). Global patterns in human consumption of net primary production. *Nature, 429*, 870 - 873.

Kay, J., & Schneider, E. (1994). Embracing complexity: The challenge of the ecosystem approach. In L. Westra & J. Lemons (Eds.), *Perspectives on Ecological Integrity* (pp. 49-59). Kluwer: Dodrecht.

Kellert, S. R. (2005). *Building for life*. Washington DC: Island Press.

Kelly, K. (1994). *Out of control - the new biology of machines*. London: Fourth Estate.

Kibert, C. J., Sendzimir, J., & Guy, G. B. (2002). *Construction ecology*. New York: Spon Press.

Korhonen, J. (2001). Four ecosystem principles for an industrial ecosystem. *Journal of Cleaner Production, 9*, 253-259.

Korten, D. (2007, April 25-27). *Presentation* at the Living Future Conference, Seattle, WA.

McDonough, W., & Braungart, M. (2002). *Cradle to cradle - remaking the way we make things*. New York: North Point Press.

Odum, E. P. (1969). The strategy of ecosystem development. *Science, 164*, 262-270.

Pedersen Zari, M. (2007 June 1-3). *Biomimetic approaches to architecture.* Poster presented at the Toronto Sustainable Building Conference 07, Toronto, Canada.

Reap, J., Baumeister, D., & Bras, B. (2005). *Holism, biomimicry and sustainable engineering.* Paper presented at the ASME International Mechanical Engineering Conference and Exposition, Orlando, FL.

Reed, B. (2006) Shifting our Mental Model - “Sustainability” to Regeneration. *Rethinking Sustainable Construction 2006: Next Generation Green Buildings.* Sarasota, Florida.

Rosemond, A. D., & Anderson, C. B. (2003). Engineering role models: Do non-human species have the answers? *Ecological Engineering, 20*, 379-387.

Shear McCann, K. (2000). The diversity-stability debate. *Nature, 405*, 228-233.

Storey, J. B., & Pedersen Zari, M. (2006). *Factor X - well being as a key component of next generation green buildings.* Rethinking Sustainable Construction Conference, Sarasota, Florida.

Thompson, D. W. (1942). *On growth and form* (2nd ed.). Cambridge: Cambridge University Press.

Van der Ryn, S. (2005). *Design for life: the architecture of Sim Van der Ryn*. Salt Lake City: Gibbs

Vincent, J. (2002). Systematic technology transfer from biology to engineering. *Philosophical Transactions of the Royal Society, 360*, 159-173.

Vincent, J. F. V., Bogatyreva, O. A., Bogatyrev, N. R., Bowyer, A., & Pahl, A.-K. (2006). Biomimetics - its practice and theory, *Journal of the Royal Society Interface*: The Royal Society.

Vogel, S. (1998). *Cat's paws and catapults*. New York: Norton and Company.

Xiong, J., & Bauer, C. E. (2002). Complex evolution of photosynthesis. *Annual Review of Plant Biology, vol. 53*, pp. 503 - 521.

Practices and sustainable principles of the rural constructions in Molise Region (Italy)

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ABSTRACT: Rural landscape of Molise is defined by three natural materials: stone, wood and clay. Thick load-bearing walls capture light, sun and heat. Rural constructions are built according to a local tradition always respectful of natural environment, kept through time and space. Everything is made of poor materials, but, nevertheless, it is a system where environment and human presence are kept in balance. In a simple and natural way, landscape represents a "super-system" in which equilibrium is obtained by simple solutions, concerning as rural houses as landscape preservation. The study of small rural buildings and their environmental impact represents a preliminary step to a sustainable recovering. It gives us the chance to investigate bioclimatic principles which were the bases of cultural and traditional values.

1 RURAL LANDSCAPE AND NATURAL MATERIALS

Each rural house leaves the traces of human being in the landscape. The houses and other rural constructions, which are linked with the housing, grow out by the working and the transformations of natural materials. These constructions can be considerate as the result of bio-ecological and bioclimatic principles which are linked to the ancient working tradition.
The rural landscape of Molise is the result of the interaction of stone, clay and wood with environmental factors. In particular the rural house is characterised by economizing policy and environmental respect. Only the available natural resources are used on the building to guarantee the environmental preservation (Ausiello 2007).
The white lime-stone is very common in countryside, both in the wood and on cultivate land. The Matese mountain is characterized by lime-stone crests; along the Biferno river valley there are a lot of rocks, so that each place could have been a pit. (Ausiello 2001)

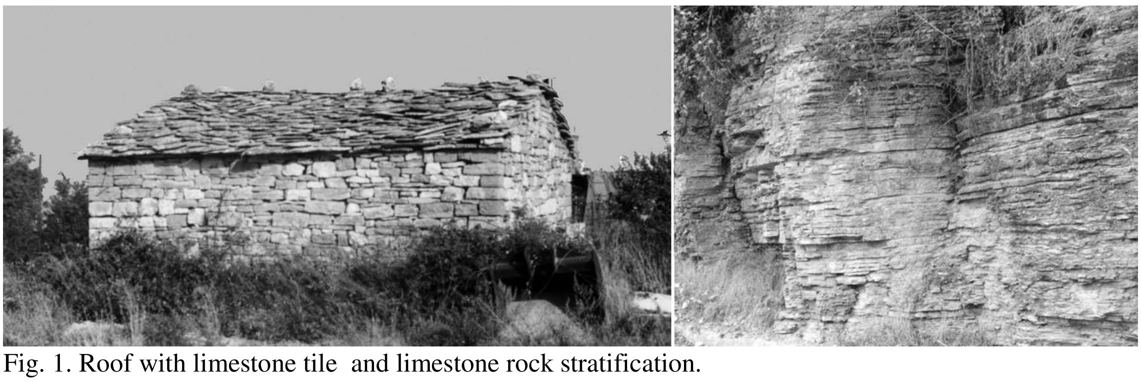
Fig. 1. Roof with limestone tile and limestone rock stratification.

The farmer collected the erratic stones on the border of fields to build some dry-stone border walls or to reuse that stones on building. Around *Frosolone (IS)* there are particular sedimentary lime rock which are constituted by different sedimentary layers of about 4 cm thick. These kind of stones were used as tiles on the roof. (Ausiello 2006)
The rural construction is a system made by a constant equilibrium between the environment and the human activities. In the same way it is possible to say that the landscape is a *super-system* based on simple and sustainable building solutions: these principles are at the base of the landscape preservation.
The study of the constructive solutions, which are respectful of the environment, is an introduction to the recovery of the landscape. This has to start from cultural values and from examples which are liked with sustainable principles. Analyzing this aspect, it is possible to deduce the ancient bioclimatic principles which have been used by the farmer-builder to set up his constructions.

2 BRICKS

In the ancient rural houses there are different kind of bricks with different dimensional shape. The form changes during the time and mainly from a brick-kiln to another. The local standard form is founded out only after the second world war. The most ancient is the handmade brick so called, in a local language, *mattonaccio* (about 13 x 26 x5,5 cm). It is very hard to recognise this brick: on the fracture surface it is possible to see bigger grain. It depends on handmade process. With modern industry the clay's quality is improved, the grain in the brick has become thinner and the brick was produced in different shapes. The useful brick form is the *pressato* (13 x 27 x 5,5 cm), then we have the *occhialone* or *bucatone* which is made with two cylindrical holes (29 x 26 x 12 cm), the *bucatiello*, with three longitudinal cylindrical or parallelepiped holes (10 x 20 x 4.5 cm), and the *mattone quadro* used as a tile-floor (20 x 20 x 1,5 cm). The old roofs are exclusively made of bent-tiles called *pingi*, the recent roof are made with a sort of plan tile called *marsigliese*.

Fig.2. Bicks*: occhialone, bucatiello, pressato, mattonaccio*, *mattone quadro* and constructive scheme with *occhialoni* and *pressati*.

The rural houses are built with poor materials, especially with lime-stones because they are already present in the environment and it needs less working time and cost than the brick. So that the use of the brick, in the bearing-wall, it is quite unusual and sometimes only the walls at first level are built with bricks. Usually the labels of the windows and doors are built with brick; it is used above all for decorative element on the walls. The *bucatone* is the main brick which is used in the bearing-walls because the assembling is easy and fast and the quantity of mortar needed is lower than the one required to build a wall with lime-stones. In the Fig.2 it is possible to see a particular wall-scheme with the *occhialone* and *pressato* which are assembled together. This scheme give the walls a major load resistance (Fig.2). The *bucatiello* is usually used to build the floor. It is built with double T-steel girders and little vault of perforated brick (*bucatiello*) which are linked with gypsum-mortar. This system is very fast because the gypsum-mortar is a quick-setting mortar so that it is necessary to use just a little cradle to built the vault. (Fig.3.) At the extrados of the little vaults, a mixture of sand and lime completes the structure of the floor. On this surface is placed the square brick as tiled floor. This construction-system became very common since the second half of the XIX century: the wood-floor is changed with the steel-floor. The progress made during this century leaves this trace in the rural world too.

Fig. 3. The intrados of a floor supported by steel girders and a wood-floor.

3 BIOCLIMATIC PRINCIPLES OF THE RURAL HOUSE

In the landscape of Molise Region, rural houses are built in a way to economize on building materials. On the other hand this kind of houses makes use of material potentiality and each environmental available resource, especially with ancient bioclimatic principles (Olgyay, 1990). In this way the heat insulating problem is partially solved using the natural resources and minimizing the heat loss. Despite building of poor materials, it represents a particular system with necessary requirement and offered performance which is a connection almost all-sufficiently. This way to built is very actual, especially because it is respectful of the sustainable principles. Thus the rural house is like an ancient prototype and, at same time, nowadays it is the demonstration that the bioclimatic principles are natural and they originate directly from the environment. In fact in the landscape the orientation of the rural houses is very particular.
In the middle of Molise Region the climate is quite cold, especially in winter, so that it is natural choosing the best exposition and preferring the position which offers more daily sunny hours. In this way, inside the dwelling, the comfort condition are quite improved. Usually along the south side of the hills it is possible to see the marks of the human being with his rural constructions. The sunny heat is accumulated into the external south walls because of the low inclination of the sun's rays during the winter (the maximum inclination at solar noon is about 25° during the winter solstice). Moreover the majority of the windows are situated on the south walls so that the sun's rays can heat the rooms inside. Instead in the summer, the sun's rays are more inclined (the maximum inclination at solar noon is about 72° during the summer solstice), so that the quantity of radiant energy, which goes inside the house through the windows, is lower than in winter (Duffie, 1978). When the ancient builder had to choose the best site to build his rural house, he has not used compass or particular instruments, he simply needed to look the sun at sunset in the winter and looked for the predominant direction of the cold wind. Therefore a lot of houses are built on the leeward side of the hill, in this way the hill side becomes a particular barrier which preserves by cold wind from E-NE. Consequently the windows on are principally situated on the south walls.

The ancient comfort-condition inside the rural dwelling were very different from nowadays. Only the kitchen was heated by a big fireplace, whereas the bedrooms were heated with a typical brazier. However some little constructive expedients have limited the loss of the heat. Inside smaller houses, with one room, the fireplace is situated on the exterior wall, whereas inside bigger houses it is situated into party-bearing-wall, so that some part of the heat moves to the opposite side of the wall thanks to a radiant heating flux. The houses situated on the plain and two-storied, have the fireplace placed at the ground-floor and their flue is capable to generate, through its thin walls, a radiant heating flux in the room upstairs. Instead in the houses built along a hill side, the stable was situated on the ground floor and on the first floor there is the living zone. In this case the heat product by cows was absorbed by the walls and the floor which exchanged radiant heat with the room upstairs.

Fig. 4. South and north façade of a typical rural house.

The thickness of the walls is oversized related to the static, however they have a good thermal inertia. They are commonly made of limestone and lime-mortar whose thickness is about 80 cm at the ground-floor and about 60 cm at first floor. This is a natural way to capture heat during a sunny day and give it back inside during the night. The windows and the doors were very rudimentary with respect to the modern ones. Usually the main door is made of elm-tree wood or oak-tree wood; the thickness is up to 8 cm. The windows are made of chestnut-tree wood and they are made with two inside shutters which are closed at the evening (Fig.5) The reason of that is mainly the thermal insulation. Different solution are obtained with double windows: one internal and one external. The first one is made by two big and thick shouters; the second one is made of wood and glass and it is placed at the border of the wall. The thermal insulation is not a modern invention, there are a lot of natural materials which have insulating properties. The ash, which is product by the firewood, is a good insulating material (Ausiello 2000).

Fig. 5. Inside and outside view of a typical window and a double window.

Each fireplace is built with a layer of ash (about 10 cm thick) below the fire-plan. In fact the ash is necessary to insulate the fireplace from the soil or the floor and the heat could be stored in the fire-plane who was made by a particular fire-brick (about 50 x 50 x 5h cm).
The same technique is used to build the wood-oven, which is present in each kitchen. It is composed by an horizontal plan and a vault which are made by fire-brick. Below the plan and above the vault there is a layer of ash to avoid heating loss. In fact the wood is burnt inside the oven, as soon as the oven is over-heat, the fire is thrown away and the oven is ready. The food, especially bread, is baked by radiant-heat from vault and contact-heat from the horizontal plan. Usually the oven is beside the fireplace, so the flue of the oven is joined with the flue of the fireplace. (Fig.6).

Fig. 6. A typical Kitchen: the wood-oven and fireplace system and the roll paint on the wall.

4 THE COLORS OF THE RURAL HOUSES

In the Molise Region, the rural architecture is distinguishable by light and pastel colours, while the landscape shows bright colours whose variations depend on the cultivations and the seasons: green in spring, yellow-ochre in summer, brown in autumn and white in winter. Each rural construction is like a human mark which transform the natural landscape in an agrarian landscape. White, pink, light-blue, brick-colour, are the colour of rural construction which are the colours of the landscape at the same time. And these colours are produced by natural processes and natural materials. Each part of the rural house is identified by a particular colour. The facade usually is pink or white, less frequently is light-blue. The warehouses, especially those for agricultural use, are made without a layer of plaster but just the joints between the stones are covered with a small quantity of lime-mortar, so that it is possible to distinguish the lime stones in a light-grey colour.

Fig.7. House with blue floor-tile under the eaves and house painted in pink colour with white bands.

The corner-bands, the edge of doors and windows are white coloured. Sometimes the label of doors and windows are built with brick and painted in white with lime-paint. The big aesthetic value of the rural house come from a traditional way to build, in fact on each ancient construction is it possible to see these particular aspects. Another characteristic element is the eaves which are built with a particular system of bent-tile. This system is called *Romanella* and below it is painted a white or blue band. Sometimes this band is constituted by blue floor-tiles (Fig.8).

Fig.8. The decoration on the facades and the typical eaves called *Romanella*.

The inside space is painted in light colour, pink, green, blue. Very typical, especially in the kitchen, are the roll-paints which represent flowers painted in blue or green on the white background of the walls. The colours of the windows are brighter than the colour of wood. Nowadays it is difficult to find out the original colour, but the original windows are painted in green outside and in white inside. This rule is the same for the external doors, whereas inside the doors are painted in white or grey (Ausiello 2001).

5 PAINTS

The making of the paint are based on the use of natural element and professional secrets which are handed on from the farmer-builder.

The paint is a fluid product which is made of water, lime-milk, animal glue and natural pigment. The paint is absorbed from the surface of walls and it creates a thin decorative and protective layer. The paints which are used to decorate the furniture are also made by natural oils.

The most simple paint is made of lime-milk which is obtained adding a lot of water in the lime-paste but it is impossible to preserve this kind of paint during the time. However it is used as disinfectant because of the lime’s natural bactericidal power. This property is very useful in the rural surroundings, in fact, at least one time a year, the walls of the stable were painted with this particular mixture using a rudimental brush.

A more durable paint is made adding some *gelatin* as the *fish-glue*, a special animal glue which is obtained by the bladder of some fishes. This is a product which is possible to buy in tablet form and it needs to be melted in hot water for few minutes.

Instead of the fish-glue, it is possible to use the *casein* which is a by-product of the milk. It is obtained by adding white vinegar or lemon juice to the milk after that some flakes appear floating on the milk. Thus the *casein* is the result of melting these flakes in tepid water. The *gelatin* is a good product to obtain a water-repellent paint.

The colour is obtained with some pigments which are mixed whit the protein paint. The most common pigments are constituted by ochre, yellow or red clay. Maybe the blue was obtained with *copper sulphate*.

6 CONCLUTIONS

This paper is a part of a research, still in progress, and is aimed at the recovery of the landscape in the central part of Molise Region. Especially in the rural environment, each kind of constructions and materials has to be analyzed because of their intrinsic eco-compatible properties. These analysis is necessary before to indicate any preserving strategies and recovering techniques. Each modern technique is the result of ancient experiment, so that the modern designer have to apply the ancient bioclimatic and bio-ecological principles in the same way. At the same time he has to choice the ancient constructive techniques which are actually. For example the choice of the orientation and the distribution of the windows are very important like so the choice of natural materials of the landscape is still sustainable.

7 REFERENCES

Ausiello G., Fornaro D. 2007. The use of the stone in the Samnites architecture. In international conference and exhibition *Stone building between innovation and tradition,* 22-23 February 2007. Napoli: Luciano Editore.

Ausiello G., Fornaro D. 2006. Il costruito minore nel paesaggio rurale del molise. Le coperture in pietra. In international conference A*rchitettura e tecnica delle coperture. Storia, tecnologie, progetti dal sistema ai temi generali dell'involucro*, Ancona 10-12 March 2006.

Ausiello G. 2001. Un angolo di paesaggio rurale nel basso Molise. In *Habitat rurale mediterraneo. Ricerche del Cittam 2000*. Napoli: Luciano Editore.

Ausiello G., 2000. *Il paesaggio rurale della Campania, architettura e caratteri costruttivi*. Napoli: Luciano Editore.

Olgyay V., 1990. *Progettare con il clima*. Padova: Franco Muzzio Editore.

Duffie J.A., Beckman W.A., 1978. *Solar Energy Thermal Process*. Napoli: Liguori Editore.

Notes

This paper is written by the authors all together. In particular the paragraphs *Rural landscape and natural materials*, *Bricks* and *The colors of the rural houses* have been assigned to G. Ausiello and the paragraphs *Bioclimatic principles of the rural house* and *Paints* have been assigned to D. Fornaro.

Environmental performance and management of sustainable urban projects

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ABSTRACT: We developed a methodological framework allowing us to model the actions carried out collectively and individually by the project group. This methodology takes its origin from the strategic analysis suggested by Crozier and Friedberg. It aims objectively to anticipate convergences or "interplays of co-operation" and divergences or "interplays of conflicts" between the main participants in urban development. The project group, as a sociological system, exists by the interdependence of participants and actions whose objectives can converge or diverge. Individual strategies are analysed to determine the collective actions necessary for success. The municipality can then organize the running of the project in accordance with the participants' inherent stopping points. Our approach places each player within the environmental management of an operation. The tool developed on this methodological basis makes it possible to display several sociograms representing direct influences between participants and the impact of each participant on the objectives of an operation.

1 GENERAL CONTEXT OF THE STUDY

Since the launch of the programme "Ecology and Habitat" by the "Construction and Architecture Plan" in 1993, operators in the field of construction have progressively mobilised to promote the environmental quality of buildings. Once the first completed projects finally saw the light of day and a very large number of operations were currently in the design or construction stage in France, the formalisation of a system of certification for these operations - HQE"® - based on a clarified normative framework was called for and has been a tangible reality since 2005.

However, although the operators in the field of construction wish to make a real response to the challenges laid down during the United Nations Conference on the Environment and Development held in Rio de Janeiro in 1992, the environmental management of HQE® operations is no longer in itself sufficient at the level of buildings alone, but must perceive itself in a wider global concept of the " habitat" at urban level. Our "Habitat" may indeed play a decisive role in bringing out new forms of association making it possible, on a daily basis, to reconcile preservation of the environment with economic efficiency and social equity. Such are the challenges that the 21st century habitat should be meeting.

Taking into account the significant number of housing developments or Designated Development Zones classed as "sustainable" currently being set up or under construction, recent years have seen an increase in the expectations of planners and municipalities that a systematic framework should be put forward, based on assessment tools adapted to suit the context of each urban project.

Our work places us at the meeting point of these expectations regarding:

- the widening of the field of environmental quality in buildings at urban planning level,
- the promotion of the consideration of environmental or socio-economic themes in development projects,
- the setting up of operational tools for assessing sustainability to be used by players in the field of urban planning

The work presented within the framework of "SUSTAINABLE BUILDING 2007" forms part of the direct consequences of research developed from the project "ADEQUA " and the expert reports commissioned by a number of municipalities.

2 PROPOSAL FOR A SYSTEM OF MANAGEMENT BY PARTICIPANTS

Many pieces of work have focused on the compilation of sets of indicators making it possible to assess the results obtained in quantitative or qualitative terms. Now, the initial feedback shows that obtaining these performance figures depends largely on the management of the operation. However, the methodological questions regarding urban management have hitherto rarely been approached. It therefore appears essential to consolidate a proposal for a system of management that is integrated, structured and organised so as to articulate the questions of sustainable development during the various stages of a development operation

Our initial investigations clearly highlight the importance of developing, within a context that is often contentious, tools making it possible to assist a municipality in its decisions or negotiations. The proposed methodology aims to place the participants at the heart of our approach before moving on to the technical performance levels that are to be achieved within the framework of this type of operation. We will draw our inspiration from the theory of the strategic player as well as the strategic forecast. The strategic analysis proposed by Crozier and Friedberg allows us in effect to model the actions led collectively and individually by the project group. The individual is here included as both the actual person and the body that he represents within the project team. Each action or system of concrete action calls upon a set of mutually interdependent participants. The system exists through the very interdependence of actions and participants, whose own objectives may converge or diverge. Our method of analysis aims objectively to anticipate the convergences or "interplays of cooperation" and the divergences or "interplays of conflicts" between the principal players in the urban development operation. This analysis therefore starts with each participant and their individual strategies, and then makes it possible to put together the collective actions necessary for the success of the operation. It must allow the municipality to organise the running of the project according to what are likely to be the participants' inherent stopping points.

By starting from the premise that each participant is a key element in the sociological organisation of the urban development operation, we recognise that the project team is made up of interdependent participants playing a role that is defined in contractual terms. The actions of each participant have a direct influence on those of the others, thus obliging everyone to adapt to new interactions. In this way, the action of some feeds the action of others, even if they have opposing interests. Divergence becomes complementary, which leads to some complexity and involves new, endlessly repeated adaptation. As stated by P. BERNOUX in the sociology of organisations, each player is a strategic being seeking to satisfy his own needs. He acts according to his own logic, rationality, and individual strategy. By creating his own room for manoeuvre, he adapts his own resources to meet the expected objectives depending on the operational environment in which he finds himself. It is because he is in a relationship with the other participants that he will conceive that he may have priorities (for example, between the short term, which concerns this project, and the long term regarding another project).

The method of analysing the set of participants that we propose to use is based on the MACTOR method developed at LIPSOR, (Laboratory for Investigation into Prospective Strategy and Organisation. This mathematical tool, that can be found in companies' long-term planning, has the principal advantage of being highly operations-focused, even with a large number of participants, as is the case within the framework of a development operation. This tool makes it possible to display a number of sociograms, schematic representations of the relationships between the players, ie. disputes, alliances, dependences, etc. We should point out that the quality of the data provided through the goodwill of the participants has a strong influence on the results. For this reason, it seems to us essential to show a zone of uncertainty corresponding to the faults of the system and producing zero-quality results, whether this is due to the pressures and deadlocks involved in the project, to professional habits … or quite simply to the fact that a participant does not yet know how he will position himself. The use of this tool requires the collection and entry of the following data:

- description and list of participants
- description and list of objectives
- entry of data in matrices for Direct Influence of Participants (MID)
- entry of data in matrices for Participants’ Objectives (MAO).

The application of the Mactor method makes it possible to obtain two types of information: the direct influences between players and the valency of each participant regarding the contractual objectives of the operation.

The results drawn from the matrices of entered data are represented in the form of a matrix of Direct and Indirect Influences (MIDI) summarising the interactions between the participants. This matrix is obtained by taking into account both the degree of direct and indirect influence of each player by counting the direct and indirect influences of the player, and the degree of direct and indirect dependence of each player by counting the clear direct and indirect dependences of the player.

By taking account of these influences and dependences, we can then determine the ‘balance of power’ held by each participant. Furthermore, it is also possible to describe the valency of each participant with regard to the objectives of the operation.

3 CASE STUDY: THE MÉRIGOTTE NEIGHBORHOOD IN POITIERS

The neighborhood of Mérigotte, figure 1, is situated close to the centre of Poitiers, between Artillery Park in the west and the railway and the slopes by the Clain to the south. The urban project designed by AUP provides for several spaces that provide structure, reinforced pedestrian walkways, three viewpoints opening up the perspectives and, above all, a green corridor linking the town with the environment.

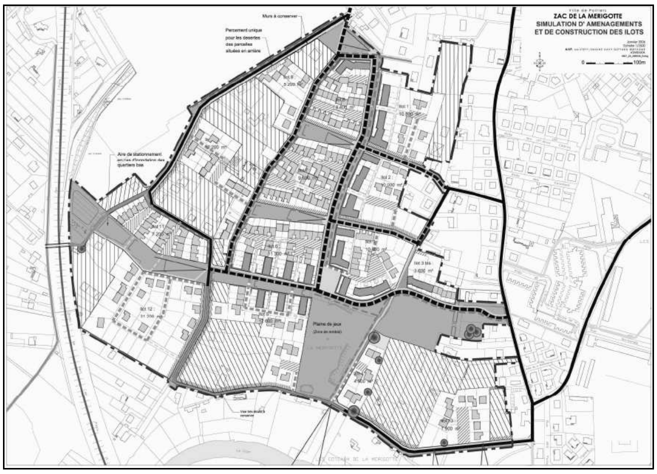

Figure 1. *Development plan produced by AUP in January 2006.*

OBJECTIVES	Conditions of contract for transfer/sale of land – DDZ
Energy efficiency	HPE label (*High Energy Efficiency*)
Management of water	Management of waste water for each plot Promote reduction in consumption of drinking water
Air quality / Health	Choose products listed as Class F + (fungistatic) Class B+ (bacteriostatic) R+ (very low radioactive emissions) C+ (very low chemical emissions) Alkyd paints or those meeting French environmental norms
“Green” building site	Organisation of site Checks and monitoring Keeping riverside residents informed Ensuring personnel’s awareness Limitation of nuisance Limitation of health risks Limitation of pollution Selective handling of waste products

Figure 2. *Contractual objectives of the Mérigotte Neighborhood.*

In order to put together the table of players’ strategies, we have identified a number of participants and initial objectives:

- The municipality, the Town of Poitiers (CP)
- The developer, ATARAXIA Development (A)
- A sample of private and public developers from amongst the principal players: OPARC, SIP, RAGONNEAU Foncier, FONCIER Service, ERMES, (P1, P2, P3).

Each player selected has been identified by means of a non-directive interview making it possible to specify his goals and objectives, plus his strengths and weaknesses.

The first result that we can draw concerns the influences and dependences between the principal players selected for the study. In Figure 3, we may observe a significant dispersal between the participants. Overall, the role played by the Town of Poitiers within the framework of this operation is highly decisive, more so than that observed on the part of the main or subsidiary developers. The coordination and monitoring of the sustainable development process is therefore wholly incumbent on the municipality. In contrast to other operations in which the developer plays the role of an intersecting player, in this case the Town of Poitiers combines the functions of coordination, steering, negotiation, monitoring, etc., of the process that it plans to carry through itself.

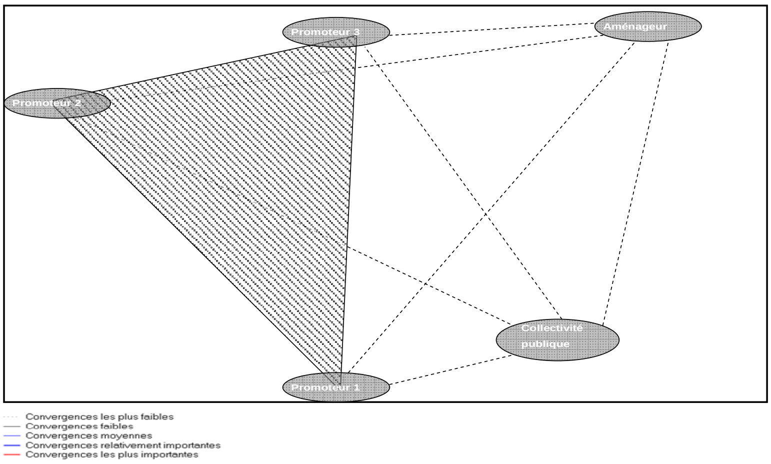

Figure 3. *Graph of convergences*

The net balance of direct and indirect influences places the developer in particular outside the other participants, taking into account his potential for influence. The graph of convergences between players, figure 3, also shows the closeness of interests shared by the municipality and the developers. This represents an important guarantee of success in all the objectives linked directly to the “building” level. What is more, divergences on this subject are zero!

On the basis of non-directive interviews, we have also been able to draw up a histogram, figure 4, showing the involvement of all the participants in relation to the selected objectives. The favourable results obtained show a very good appropriation of the approach desired by the municipality, above all in matters relating to water and energy. The measured divergences are here also negligible. This would seem to demonstrate a fairly good level of cohesion between the participants with regard to the approach proposed by the municipality.

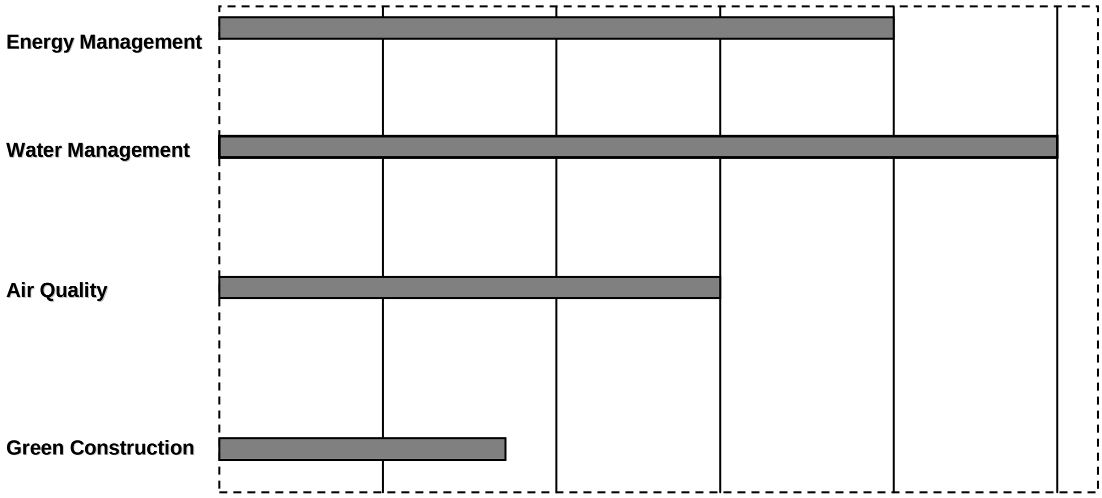

Figure 4. *Histogram showing involvement of participants with regard to objectives*

We must also point out that here is no ambivalence on the part of any of the participants, which reinforces our reading of the above results. The level of convergence and the appropriation of the approach to sustainable development have brought all the participants together in a highly positive manner.

4 CONCLUSIONS AND PROSPECTS

This first application confirms our faith in the feasibility and relevance of our approach. We planned to model various development operations in this way in order to acquire and give structure to knowledge regarding the drawing-up of projects. Our objective is not to rationalise the action being taken. Modelling is not seen here as a predictive model, in other words for putting things in order. The objective is to acquire a better knowledge of the conditions under which the project is put together in order to improve organisation, in the knowledge that each project is unique.

We are seeking to model practices, to understand how decisions are organised and what the rules are governing actions and deliberations. If, within a project, each participant has the right to speak, one may wonder about the value attributed to it according to its origin, about the hierarchical structure and how it is constructed.

5 BIBLIOGRAPHY

Association 4D, 2003, Politique de la ville et développement urbain durable, Rapport final Délégation Interministérielle à la Ville.

Bernoux P., 1985, La sociologie des organisations, Edition du Seuil, Paris.

Charlot-Valdieu C., 2004, « Présentation de la démarche HQE2R et de ses principaux outil », Conférence européenne « Aménagement et Renouvellement Urbain Durable », Cannes.

Cherqui F., 2005, Méthodologie d'évaluation d'un projet d'aménagement durable d'un quartier, Thèse de doctorat, Université de La Rochelle.

Crozier M., Friedberg E., 1992, L'acteur et le système, Editions du Seuil, Paris.

Descartes R., 1637, Discours de la méthode, éd. De Cluny, Paris.

De Rosnay J., 1975, Le macroscope : vers une vision globale, éd. Du Seuil, Paris.

Godet M., 2001, Manuel de prospective stratégique, Dunod, Paris.

Le Moigne J.L., 1974, Les systèmes de décision dans les organisations, Presses Universitaires de France.

Le Moigne J.L., 1983, La théorie du système général, Théorie de la modélisation, Presses Universitaires de France, Paris.

Morin E., 1982, Science avec conscience, éd. Fayard, Paris.

PASTILLE, 2002, Les indicateurs en action, Développement durable, indicateurs et aide à la décision : l'empreinte locale, Rapport final, Bruxelles.

SNAL, 2005, Méthodologie pour une démarche de qualité environnementale sur les opérations d'aménagement dans une perspective de développement durable, SETUR, Paris.

Assessment on urban ecosystems?

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ABSTRACT: Urbanization based on extensive consume of fossil fuels has long term environmental costs that citizens and users of urbanized territories will soon pay with lost of life quality, as with limitation of access to natural resources. Nowadays, those costs are not included on territory management decisions, but academics agree that new sustainability assessment methods are needed to internalize them, to empower administration on the control from urban environmental costs, measuring the sustainability of urban development on a certain territory and re-thinking models and strategies.
Recognizing that it is impossible to achieve all at once the long wished “sustainable city”, several doubts emerge which will be discussed along this paper: How to define an urban ecosystem and within which territorial limits to control it? Which should be the “eco urban system” model behind sustainability assessment? And how to distribute environmental costs and benefits brought by certain sustainability strategies and measures?

1 INTRODUCTION

Theoretically a sustainable urban ecosystem should manage its natural resources in a “closed loop”, minimizing the risk of environmental damage and rupture, while controlling flows of resources and reduce its losses (energy, materials and information). Urban sustainability assessment should follow this general aim, also for the reality of contemporary urban systems based on nets of mobility, on new extensive housing and on new spaces for consume and leisure.

The development of efficient tools to measure and to control materials and energy flows on the “urban ecosystem” demands technical knowledge about the basic biogeochemical cycles (carbon, water, soil, minerals) but also demands efficient political tools to inform decisions on planning and drawing future urban systems. Strategic indicators are precisely tools to translate technical knowledge into political decision, and allow clarifying costs and benefits of different urbanization solutions, as its impacts on the long term environmental quality of urbanized space, at its different scales.

More than ever, infrastructure, urbanization, nets of mobility and housing are intense generators of unsustainable land uses and irreversible deterioration of the environment, threatening the reserves of low entropy from the biosphere and the eco-efficiency from the support systems (Naredo, 2003). The idea of “urban sustainable development”, in this sense, seems to be an oxymoron, seen that to increase population density where the resources are already dilapidated – the urban regions - can be incompatible with the idea of sustainability (Forman, 1995).

Even that nowadays it’s from the common agreement that the concept of environmental sustainability demands measurable parameters based on the biosphere cycles and its capacity to regenerate life on Earth (Wackernagel, 1996), assessment on urban planning lacks the definition of what is “*an environmentally sustainable urban system*” (see point 3) and misses consensual rules for the relations that this urban system should establish with the ecosystem that supports it.

Without these definitions and rules, while working on a physical support where free-goods as air, water, and ecosystem stability are neglected (Martinez-Alier, 1998), neither strategic environmental assessment (SEA) approach, neither urbanistic sciences, were able to produce tools to drive urban development and urban design into eco-efficiency objectives on a constructive and equal way for all the agents evolved, assuring a more sustainable urban environment.

This paper recognizes and explains the need of such tools, and although not proposing still a new tool, it presents the fundamental doubts to face before producing it, clarifying the domain of urban ecology applied to urban planning.

2 IS THERE AN URBAN-ECOSYSTEM; WITHIN WHICH LIMITS?

Ecosystems are based in materials, energy and information, and its complexity depend on the "information" as form of organization of the system (Margalef, 1993). From the thermodynamic point of view natural ecosystems are systems away from equilibrium that auto organize them selves increasing the level of disorder, or entropy, on its surrounding environment (Terradas, 2001). This means that they take continuously energy from its environment and dissipate it in non profitable ways. It means also that without the input of solar of energy they could not increase its internal order, for what they are considerate dissipative structures.

Cities and socio economical systems are also dissipative structures and its dissipation translates into increase of disorder in the natural environment that surrounds it, what means increase of entropy, and so increase of unsustainability (Idem). An urban system is one form of organization of a group of flows similar with an ecological system (Margalef, 1993), existing a strong connection between economical flows and flows of materials, services and energy crossing the urban system (Georgescu-Roegen, 1996).

One of the first authors who refers the city as an ecosystem is Odum, who defines it as a heterotrophic system depending on large areas, contiguous and not contiguous, to collect resources. According to this author, the city differs from a natural heterotrophic ecosystem because it presents a much more intense metabolic rate for unity of area, demanding a much higher concentrated supply of energy and producing much more waste (Odum, 1980 [1971]).

Another difference between urban and natural systems is pointed by Margalef, when showing that urban ecosystems are horizontal transport depending, while on natural ones is the vertical transportations of organic materials that establishes the continuity of biogeochemical cycles, in flows that determinate the system productivity (Margalef, 1993). And in reality, on a globalised world, the complexity and extension of horizontal transport flows distort easily the limits from urban-ecosystems.

Biogeochemical cycles produced on urban and rural industrialized environment are not comparable to the ones produced on natural ecosystems, for industrialized society is based on open cycles as biosphere on closed ones. Trying to capture and relate this open cycles, Odum refers that the city ecology depends on the country ecology, and that the urban ecosystem is only complete when the "environments of entrance and exit" (areas of resources supply of and waste absorption) are included. This vision goes along with the opinion of Bettini who defends that until the dichotomy urban vs. rural won't be broken; city ecosystem management will remain as pure theory (Bettini, 1998). This approach seems suitable to contemporary urban forms where the limit between city and country is long lost, as to the emergent polycentric urban structures where rural (productive) soil is mixed with urban soil (non productive) on a global territory, as at the old models of the garden cities (Howard, 1998 [1904]). However, the analysis and management from the areas of territorial resources supply of and waste absorption can turn unfeasible when rural areas which provide urban supply are spread all over the Planet, alongside extensive nets.

On the approach to landscapes and regions as "land mosaics" (Forman, 1995), and integrating equally urban and rural uses of soil as key areas to sustainability of environments and Landscapes, the problem of limits and dimensions also emerge: where does a green corridor start and finish? Where do the flows of resources enter or leave the system? Delimitating these "interfaces" areas is a complex task but essential to the study of material and energetic metabolism from ecosystems of any type.

On the urban field – a territory of crossings where a large quantity of information is transferred – the flows are regulated through decisions with several origins and scales, influenced by culture, by knowledge, by the relations and economical activities, making it even harder to understand than in natural ecosystems (Terradas, 2001).

On Martinez-Alier vision there is a basic difference between human ecology and animal ecology: human territoriality, in its geographical distribution and its restrictions to migrations is not produced from nature and cannot be explained by ethologic analogies. And precisely due to the specificity of human territoriality and its "artificial" geographical distribution, the definition of carrying capacity as become irrelevant to human communities. This was not only caused by migration tendency, but also by the occurrence of international trade, which became an appropriation of the carrying capacity from other countries (Martinez-Alier, 1998).

As synthesis, we can say that on a society detached from its physical "ground" urban-ecosystems are diffuse and its delimitation should strategically identify boundaries and interfaces related to the environmental analysis and eco-efficiency purposes.

3 WHAT IS AN ENVIRONMENTALLY SUSTAINABLE URBAN SYSTEM?

The difference between natural and urban ecosystems sustainability relies on the fact that the biosphere is able to process the "restitution of order" only at the expenses of entropic degradation of sun, while conventional urban systems (and other humanized territorial systems as the intensive rural ones) cannot reorganize themselves without external resources as fossil fuels, and extensive production of waste and contamination, maximizing the increase of entropy on the receptive environment (Naredo; Valero, 1999).

If the resources consumed on an urban system would be used in closed cycles, with the minimum of losses, and controlled by the limits of the local biospheric support, its eco-efficiency would be assured, the increase of entropy caused on the environment would be minimized, and its environmental sustainability would achieve high levels. In reality, several traditional organic societies knew how to do it (Laureano, 1998).

To discuss this model of environmentally sustainable urban system we should speak from eco-efficiency. Efficiency, as known, can be measured as the capacity to produce a utility with the minimum of resources. The difference between efficiency and eco-efficiency relies on the fact that only the last one aims to obtain "utility" assuring that the used resources are renewable in quality at long term, and at an equivalent rhythm to the one in which they are being consumed. Since achieving conventional efficiency it's possible only reducing resources consume in quantity, on a present moment, several authors sustain that conventional economy "discounts the future on the price of products" showing how wrong can be its bases (Wackernagel, 1996).

Eco-efficiency of a system can only be evaluated if its "utility" is known. But which is the utility of an urban system? On what respects to buildings, "habitability" has been pointed as its utility, and so its eco-efficiency is measured comparing the natural resources consumed to obtain this "habitability" in a continuous way (Cuchí, 2006). However, considering the urban system, what is the "service" that it produces? Can this "service" be provided on a more or less eco-efficient way?

Accessibility, agglomeration, spatial interaction, hierarchy and competitivety are the five principles of urban systems pointed by the recent urban economy (Camagni, 2003). Coincidence and difference are main qualities of the city, symbolized by the "urban corner" (Sola-Morales, 2004). Are these the "services" that an urban system should produce on a sustainable way, consuming natural resources on a closed loop, assuring its renovation on short term and keeping the natural capital constant? Or such elements don't depend directly of natural resources, rather than on people and on urban form and its uses?

Urban systems are integrated into a transterritorial net of transactions moved by the physical net of transport and communication, where cities are the nodes. On this perspective, the utility, or the function, of urban system could be defined as "connectivity and accessibility to places, persons and resources". If we agree that the urban artefact is an articulated space to provide people and activities interaction, we can say that urbanity is not a question of density, but a question of interdependency. In this sense, how to relate it to an efficient use of natural resources? This would demand to replace "city" by "urbanization" as subject of environmental evaluation, what means to replace social interdependency by physical infra structure. Indeed, even than partial, this seems the only possible way for an operative urban environmental sustainability assessment.

If we focus on the canonical city, there are several models available to base strategies of environmental sustainability of urban projects. The most known examples are the North-European neighbourhoods produced on the context of the Agendas 21, namely the German cases of Kronsberg and Freiburg (LNEC, 2005), normally electing one specific theme inside the palette of environmental sustainability: water recycling; energetic optimization, public participation. These cases are interesting but don't aim to offer a universal model, and it is hard to extract from them bases for assessment due to the particular contexts which had generate them.

The Urban Ecology Agency of Barcelona, on the aim of the Local Agenda 21 from this city, has produced a model based on the agglomeration of nine blocks of the XIX century Cerdá grid, assuring sustainable mobility – walking, biking and public transports – on the central city (Rueda, 2006). Actually the Agency is trying to adapt this model to other Spanish cities, through the implementation of indicators that regulate urbanistic activities. This indicators result from the four principles of urban sustainability used by the Agency: compacity; diversity; efficiency and stability, which can be synthesized on the sustainability guide function from the Urban Ecology Agency of Barcelona:

$$\text{Urban Efficiency} = E/H$$

E correspond to the resources consumed (converted in energy unities) and H to the complexity achieved (H corresponds to the "information" defined by Margalef, measured in bytes). The first problem of this formula is how to measure H (complexity) and the second how to define its minimum value to considerer that there is an urban system to evaluate. At this point we would need to know which quantity of information and complexity distinguishes a village from a city, or a rural system from an urban one, and how to measure it at the contemporary city.

Other approaches are necessary to generate a model of intervention more compatible with the non canonical city, on its diversified mosaic of patterns, able to base comparative analyses and constructive evaluations. The approach from the Environmental Assessment and its reports has shown to be still too distant from the work of the urban planner and designer and not able to operate over critical urbanistic decisions as density and morphology of settlement.

The resources that should ground a model of environmentally sustainable urban system are quite clear: Water, carbon, soil, nitrogen and phosphor are the vital elements which circulate on the principal cycles of biosphere (Odum 1992). Without those elements and its continuous cycles agriculture, population feeding and human activities would be no long possible and territorial sustainability wouldn't be even a theme. The next problem that strategic urban environmental assessment has to face is to propose ways to manage such resources efficiently, as to measure and compare results.

4 MEASURING AND ASSESSING ECO-EFFICIENCY OF URBAN PROJECTS

As several professionals can confirm, environmental assessment and urbanism are complementary fields that still don't have enough tools in common. Strategic environmental assessment (SEA) and urbanistic studies (Master and General Plans) lead some times to similar conclusions, even that without direct interaction. The opposite ideas that "nature should determinate urbanism" (Mchargh, 1971) or that urbanism should control nature are not any more at the extremes of this dialogue. However, on the Iberian context, neither the environmental evaluations, neither the urbanistic science achieved to produce more eco-efficient urban territories - on what concerns to the reduction of natural resources requirements, with real consequences on the inputs and outputs of the urban metabolism and its sustainability.

In Portugal, environmental evaluation and assessment is a practice with reduced impact on urban form and on urban design decisions, even with all the investments of the POLIS program and the context of the SEA Directive (2001/42/CE). SEA, as known, is a process to ensure that significant environmental effects arising from policies, plans and programmes are identified, assessed, mitigated, communicated to decision-makers, monitored and that opportunities for public involvement are provided. Its purpose is to ensure that environmental consequences of certain plans and programmes are identified and assessed before their adoption. SEA was an important step further on the Environmental Impact Assessment (EIA) but it has still not the ability to generate forms of direct interaction with urban design. Although it has being used for several Land-use plans, applying indicators as soil quality, groundwater and surface water quality, air quality, noise, etc., it is not a tool addressed to “draw the sustainable city of tomorrow”. For such purpose complementary strategies of urban assessment are needed.

Measuring environmental sustainability of urban systems, or urban projects, means to relate the demand of resources, necessary to satisfy the needs of its inhabitants, with the capacity of natural capital to satisfy the demand from future times (Bettini, 1998). This capacity can be measured through the analyses of the biospheric support system, demanding information related to uses of soil, water, energy, materials and waste, and still to all the economical activities that take place on an urban region. This basic information, as the cartographic and numeric actualized registration of all the uses of the territory, although still heterogenic available, is one elemental step to approach urban sustainable assessment (Naredo; Valero, 1999).

Further than the availability of basic data, two complementary needs emerge to control the sustainability of urbanized territories in advance: In one hand, the need of *methods of reality analyses* based on indicators dedicated to the environmental understanding of each territory, and to the identification of its natural resources (soil, water, energy sources); in the other hand, the need of *plans and projects assessment methods* based on key indicators able to capture the specific potential of each territory, as its pathologies and plus values, leading the strategies of urban system design to local solutions, more than to general models.

On both kind of methods before asking the question “how to measure metabolism flows?” should be asked “what to measure for such flows?”. Measuring becomes an interesting and pertinent activity when its objectives are clear. More important than the list of indicators used by a certain urbanistic administration, are the methods and scales of its application and moderation. Not all the indicators have the same importance, the same applicability, the same qualities of measure, and not all are related to the same instruments of urban planning. What is more important water, energy or biodiversity; mobility, density, typologies or constructive systems of buildings (LNEC, 2005)?

On what concern to analyses indicators, several models are available which measure quality from soil, water and air, as biodiversity and levels of contamination and noise. However, on what concern to indicators for urbanization scenarios, the agreement about relevant parameters to measure is reduced, also due to the already discussed uncertainty about city limits and function. Strong indicators as the ecological footprint (Wackernagel, 1996) or incorporated CO2 (Pagés; Cuchí, 2006) are conceptually interesting but its applicability to urban systems is discussable. On the first case because of the complexity of measurement, on the second case because of the partiality of the indicator (it excludes territorial problems as water and soil reposition). Urban indicators as land use, soil occupation, density of settlement and connectivity, attached to environmental indicators as water, energy, waste and minerals balances seem the most productive way to lead urban and territorial sustainability assessment.

Although the carrying capacity from an urban system (in terms of density and pressure over the resources) is determined by the extension and productivity of the biospheric system from which it depends (Cuchí, 2006), urban projects are always developed into administrative or propriety limits, more than within resources supply limits. In this way, urban projects are always partial in what relates to the urban and territorial system and fragmented in what considers to its biophysical support. However, it is becoming clear that several processes of regeneration of resources are not possible inside the city as they are on enlarged territories. At this larger scale forestry, diffuse systems of depuration and other infrastructures can be planned, instead of just transferring concentrated contaminants from one side to the other how it has being done at the city scale, without solving its reutilization and elimination (Robin In Wackernagel, 1996).

As the territory cannot be designed at once, the approaches to its organization should focus on its structuring elements, grounded on the nets of flows of resources, people and goods. Urban projects fail several times on identifying these elements, and are still more attached to the interests of the promoters that to the interests of the territories and its communities.

So, measuring sustainability of urban systems through the evaluation from urban projects may not be the better route, for its starting point is already detached from a vision of strong sustainability where natural capital should have a central role.

Furthermore, urban forms today are so different of each other that it becomes evident that different typologies of cities, or different scales of urban systems, demand different types of sustainable ecosystems and different strategies of resources management. Measuring urban sustainability at the metropolis can not be the same than on the metapolis, or at the conurbation, and much less on the canonical city.

5 FACING URBAN (UN)SUSTAINABILITY COSTS

It is known that to close the loop of the use/reuse of natural resources on a certain urban ecosystem demands extra costs, from studies and projects to execution and maintenance. To invest on soil conservation and erosion control, local production of renewable energy, water recycling and waste management implies costs, with long term payback, that should not be simply allocated to the final consumer as it happens with other ecological products.

More sustainable urban systems have initial costs but bring durable environmental benefits, while conventional urban systems led without objectives of eco-efficiency, although "cheaper" can have high and irreversible environmental collective costs that are not internalized on urban management (as contamination, losses of soil or of biodiversity, unavailability of quality water, etc.). So, a balance between "costs of sustainability" (from investment on innovative infrastructures and research) and "costs of unsustainability" (from fast and waste led urbanization) should base the discussion about an effective distribution of environmental costs and benefits of urbanization on a certain territory. On this field environmental analysis indicators are useful instruments, but for the intervention on an urban system demands key indicators that beyond measuring the state of the area in study, and establishing objectives of efficiency on the use of natural resources, can strategically capture the sustainability potential of a specific territory and manage the costs of its achievement.

Joining objectives from urbanists and biologists, developers and public administrators, while leading to the best solution of intervention, is one big challenge for territory management. It leads us to the necessity of a tool to balance environmental costs, while assuring equity on the processes of transformation of land use. Such tool could internalize environmental costs from use of the collective natural capital in urban systems, as to include aims of strong sustainability on the compensations and redistribution of propriety and plus-values. This new tool could finally assure that eco-efficiency of the use of natural resources would be taken into account in the process of urbanistic management and metropolitan finance (Camagni, 2005). And in fact we should be conscientious that the challenge of increased self-reliance from urban regions won't be possible to face apart from the urban economy and its financial bases (Wackernagel, 1996).

6 CONCLUSION

In an era of increasing uncertainty and global change, dependent regions might strive both to increase local production and reduce demand from external resources. For one economy based on self sustainable bioregions, with local economies at the right scale to satisfaction of population, there are needed massive improvements on the efficiency of economical activities, so that growth in consumption of goods and services would be detached from growth in the use of energy and material (Wackernagel, 1996).

One of our main economical activities is urbanization, and such activity has largely demonstrated is environmental inefficiency, for what it needs to be submitted to new forms of regulation based on urban ecology applied to urban planning. However, this paper showed that urban environmental assessment is not only a question of ecosystem analyses indicators – usable for existent urban systems but insufficient for the evaluation and comparison of urban projects and urban transformation scenarios, and it has underlined the need of adding it strong urbanistic indicators as mediators between technical knowledge and political decision.

Several problems were showed while explaining that the urban-ecosystem is not an easily recognizable entity due to its intense metabolism; its dependency on horizontal transport; and its absence of limits.

It was demonstrated that there are no consensual models of an environmentally sustainable urban system, and were discussed forms of measuring eco-efficiency of urban projects; finally, it was presented the problem of the distribution from urban sustainability costs.

With this overview, the paper aims to call the attention for the insufficiency from environmental assessment on the regulation of urban projects eco-efficiency. Such insufficiency results of the domain of rightful objectives of environmental protection over the objectives of optimization of resources consume. In fact, protection is a fundamental component from environmental analyses, and efficiency has being less taken into account. However, the detachment from urban activities from the growth in the use of energy and material represents a true and needed improvement on eco-efficiency which should be valorised by the instruments of management of the territory. As we know such "dematerialization" of economic goods and services must proceed faster than economic growth. Only in this way will be possible to produce the necessary reduction of humanity's load on the ecosphere and then, to able a real territorial, as urban, as rural, sustainability.

REFERENCES

Bettini, V. 1998 – Elementos de Ecología Urbana - Editorial Trotta: Madrid

Camagni, R. 2005 – Economia urbana - Antoni Bosch editor: Barcelona

Cuchí, A. 2007 – El paisage como resultado de la gestíon de los recursos – Architettura del paesaggio: Milão

Forman, R. T.T. 1995 – Land Mosaics. The ecology of landscapes and regions- Cambridge University Press: Cambridge

Laureano, Pietro. 1998 - La piramide Rovesciata. Il modelo dell óasi per il pianeta Terra- Bollati Boringhieri editore: Turim

Margalef, R. 1993 – Teoría dos Sistemas Ecológicos - Publicacions UB: Barcelona

Martìnez-ALIER, J.1998 – La economía ecológica como ecología humana – F.César Manrique

Mchargh, I. 1971– Design with nature – Garden City, Doubleday: New York

Mourão, J; Pedro, J. 2005 – Sustentabilidade Ambiental da Habitação e Áreas Residenciais – Laboratório Nacional de Engenharia Civil [em publicação]

Naredo, J. M; Valero, A. (dirs.)1999 – Desarollo económico e deterioro ecológico – F. Argenteria: Madrid

Naredo, J. M. 2003– Instrumentos para paliar la insostenibilidad de los Sistemas Urbanos – in Ecologia y Ciudad - El viejo Topo

Odum, E.P. 1992– Ecología, bases científicas para un nuevo paradigma - Vedrà: Barcelona

Odum, T.H. 1980 – Ambiente, energía y sociedad - Blume ecología: Barcelona

Pagés,A; Cuchí, A. 2006 – Emissions de Co2 en el sector de l'edificació – International Conference on Sustainibility Measurement and Modelling ICSMM 06

Rueda, S. 2006 [et.al] – Plan Especial de indicadors de sostenibilidad Ambiental de la Actividad Urbanística de Sevilla: Ayuntamento de Sevilla e Agencia Local d'Ecologia Urbana de Barcelona

Terradas, J. 2001 – Ecologia Urbana - Generalitat de Catalunya - Departament de Medi Ambient: Barcelona

Wackernagel, M. e Rees W. 1996 - Our ecological footprint, Reducing Human Impact on the Earth – New Society Publishers – The New Catalyst's Bioregional Series: Gabriola Island

The compact city: an urban path towards sustainability in arid areas

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ABSTRACT: One of the principal topics dealt with as far as urban sustainability is concerned is urban form or, in another term, the morphology of the cities. It is quite obvious that the cities do not represent a single form, but whatever their form, they continue to be defined above all by their urban density. The later influences the space use and management, energy and resources, social co-education and the cost of infrastructures and services, and last but not least urban climate. This question arouses a great interest between various disciplines. This research work is a contribution to the debate on the most favourable urban forms to a sustainable urban development, in the arid areas. It presents the results of an experimental study, examining the effect of the level of the urban density and the compactness of the framework built on the climate of the town of "Biskra" in Algeria.

1 INTRODUCTION

In the debate on the subject of the cities and their impact, the question of forms and urban densities are the subject of sharp discussions. Indeed the urban density constitutes a fundamental object of study, for it becomes one of the main pathways regarding durable urban development, considering its influence on: the consumption of energy and the emission of pollutants, urban spreading out, the land use and of resources, efficiency of the infrastructures and public transport and finally urban climate. Urban forms involve a transformation of the characteristics of the surface of the ground, biosphere and climatic conditions. The latter, i.e. the involuntary modification of the climatic conditions illustrates one of principal involuntary modifications of the atmosphere by man. And it appears on all scales: global, regional, local and micro scale. At the local scale, many factors contribute to modify the climate, among them: topography, ground, vegetation, as well as the city and the anthropic activities. (Goyette-Pernot & al, 2003) In the context of the arid areas in Algeria, the results of the last research, based on the analysis of the time series of the weather factors indicated the tendency of a climatic change in a number of arid and semi arid cities. This change in the local climates of these cities is due to the intense urbanization which led to urban forms based on imported models unsuited to this context, characterized by their low density, and resulting in a considerable urban spreading out.

2 AMS OF THE STUDY

Principal aims had by this study are: firstly, to give a size to the microclimatic modifications generated by urban forms presenting levels of urban density and varied built form compactness, for the case of the arid areas, with hot and dry climate. Secondly, to find out for the studied case, the most optimal level of density and compactness, which make it possible to mitigate the negative effects on the urban microclimate. And finally, to sketch the broad outline of an urban morphology which can contribute to limit the negative effects of urbanization on local climate for the Saharan cities, and which can contribute to give birth to a sustainable city.

3 CASE STUDY

This research which will be based on a comparative study is applied to the case of the town of Biskra, pertaining to the arid areas with hot and dry climate in Algeria. Its arid climate (the Martonne index of aridity, for the last decade, is equal to: I = 4.43, indicating an absolute aridity i.e. a hyper aridity) is characterized by cold and dry winters and hot and dry summers; an annual average temperature of 22,3°C, with a minimum of 11,4°C in January and a maximum of 34,2°C in July, very weak precipitations: 200mm/an maximum.

The reading of the evolution of the process of urbanization in this city reveals an abrupt passage from traditional urban forms built in perfect harmony with the natural elements of the environment and particularly with climate, the palm plantation and water, to new urban forms based on the ZHUN standardization system and the plots resulting from standardized schemes leading to loose urban fabrics, which had a relative impact on the climate.

Along its representativeness of the arid cities, the case of the town of Biskra is selected for methodological. In fact, the realization of the study's experimentation postulates varied samples of urban fabric with varied levels of density, but which are subject to the same climatic conditions and showing similar topographic characteristics; thus the case of the town of Biskra is selected, because it offers the morphological diversity requested within the same context.

4 METHODOLOGY AND DESCRIPTION OF THE EXPERIMENT

This research is based on a comparative study, using the experimental method, in the form of data acquisition by measurement campaigns. The objective of the experiment is to qualify the microclimatic modifications due to urban forms presenting different levels of density and compactness.

4.1 Typological study and sampling

Table 1. Selected samples.

Category	Type of tissus	Chosen districts	Localization
Very dense	Traditional	M'cid	In the South, in the old city, immersed inside the palm plantation
	Unplanned self-built	Star Melouk district	The intermediate zone between the colonial district and the old city
Dense	Colonial	The colonial District	East side of the town centre.
	planned self- built (plots)	Hay El Moudjahidine plot (270 plots).	West part of the ZHUN.
Release	High rise (collective habitat)	500 logements district	Eastern ZHUN.

The sampling of this study is based on a typological analysis which includes three levels of classification. The first level: is a pre-classification on the scale of the city, various urban fabrics, according to criteria of order: urban, architectural, urbanization mode and production, as well as historical and legal criteria. The second level of classification and which will be useful for the choice of the samples, consists of assembling the types of habitat having a relatively similar density, according to standards defined by Zucchelli, and which distinguishes three cases:

- The very dense urban fabrics
- The dense urban fabrics
- The loose Urban fabrics

Thus according to a no probabilistic five typical samples were chosen, according to the established classification, while taking into account the intermediate effect of the variables, such as the vegetation and the nature of the physical mass.

Then for each selected sample, an inventory of external spaces representative of the fabric as a whole, was established according to morphological criteria of order (form, orientation, opening to the sky, materials, etc), and climatic criteria (exposure on the ground and the winds). The delimited perimeters of study, gather the totality of the morphological aspects of the sample: such as the density of the frame, the form and proportions of the small islands and plots... etc. The traced routes thus pass by all the representative spaces of the sample.

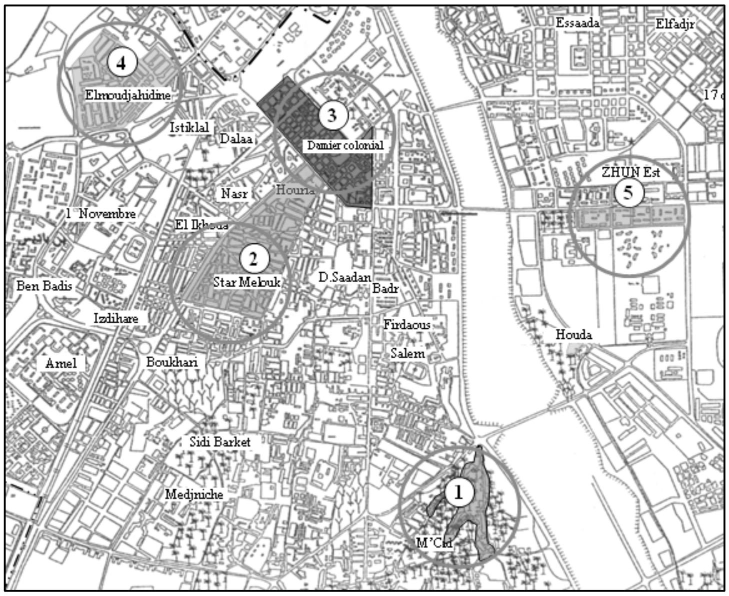

Figure 2. Localization of the retained samples.

4.2 *Density parameters*

Being interested in the density of the built form at the urban fabric scale, i.e. with a density which introduces the system of open spaces (network of roadway system and urban spaces...), recourse was made to the land occupation coefficient of for its determination. And in order to complete the acquired information, a determination of the compactness of the built framework is provided by two indicators: on the one hand the coefficient of form, and on the other hand the ratio of the exposed surfaces to other surfaces, constituting two supplementary ratios, integrating very significant parameters in energy exchanges. (Cordier & al, 1989) The results of elaborate calculations are presented in the following table.

Table 2. Determination of the level of density and compactness of the built framework.

		1st sample	2nd sample	3d sample	4th sample	5th sample
Total surface of the zone covered by the study *(m^2)*		22 249.63	113 010	131 590	79 592.82	103 133.56
Land occupation coefficient	On the level of the plot (net)	0.99	1	0.82	0.82	0.16
	On the level of the district (brut)	0.69	0.64	0.51	0.42	0.09
Form Coefficient (m^2/m^3)		0.29	0.25	0.37	0.35	0.40
Ratio no exposed surfaces/ exposed surfaces		1.92	1.05	2.58	2.37	5.53

4.3 Climatic factors measurements and system of data acquisition

The measured climatic factors are: air temperature, radiant temperature, relative humidity and air velocity. Measurements of the climatic factors are carried out by direct measurements, made using sensors located at the place where measurements are taken. The system of data acquisition is composed of a thermo hygrometer, an environment meter and an anemometer.

4.4 Course of the experiment

The measurement campaigns are carried out in three representative days of both seasons: spring and summer 2004, in five moments of the day. The selected moments are related to the daily temperature pattern:

- Before sun rising: before any thermal gain.
- After sun rising: beginning of heat gain.
- At midday: when the sun is at the zenith.
- Before sunset: after a maximum accumulated heat gain.
- After sunset: start of stored heat restitution

In order to minimize the time shift between the first and the last measurement, work was distributed over three days. While being based on ten days weather forecasting, three representative days of spring and summer seasons, were thus selected.

The results obtained are compared with a site measurements in the immediate non urbanized setting- considered unchanged: the weather station, from which the energy balance is different from that of the city. The selected data for the comparison are those extracted at the measurements times.

For the two seasons 1055 measurements were taken, 620 measurements in summer and 435 measurements in spring, bearing on 31 spaces in the city, in three representative days for each season. The experiment is made by a staff which is composed of three members - including the author -. Displacements of the team are ensured by a car. Measurements of the four examined climatic factors are made at the same moment, i.e. in parallel and they are taken with 1.60m high above the ground.

5 PRESENTATION AND ANALYSIS OF THE RESULTS

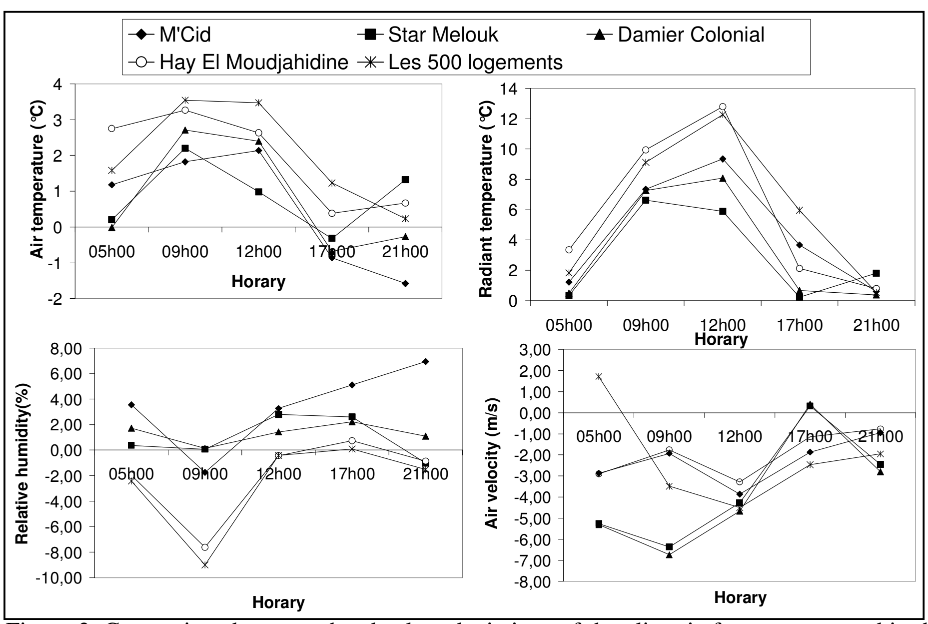

Figure 3. Comparison between the absolute deviations of the climatic factors measured in the various districts compared to the weather station (summer season).

Although the measurements days were carefully selected to represent one summer day, the fact remains that there were differences between climatic conditions in the three selected days. In order to have a reference mark of comparison, we have made recourse to the calculation of the absolute deviations of the values obtained with those recorded in the weather station, for each moment of the day (crossed courses). The variation with the value recorded in the station weather is equal to the arithmetic mean of the differences between the value recorded in each point and that recorded in the weather station.

5.1 Comparison between the absolute deviations of the air temperatures

What is ought to be said is that the progression of the average of the absolute deviations of Ait T° which goes hand in hand with the reduction in the density, as well as a progression of the average temperatures of the crossings of the post sunrise, until and before its sunset.

Progression of the absolute deviations of radT (after sunrise and until sunset) and of their average which goes hand in hand with the reduction in the density, put aside the traditional district which makes the exception because of the recent tarring, as well as the difference in the protection offered by the foliar mass (shade + evapotranspiration).

5.2 Comparison between the absolute deviations of the radiant temperatures

Progression of the absolute deviations of radiant temperature (after sunrise and until sunset) and of their average which goes hand in hand with the reduction in the density, put aside the traditional district which makes the exception because of the recent tarring, as well as the difference in the protection offered by the foliar mass (shade + evapotranspiration).

5.3 Comparison between the absolute deviations of the relative humidity

The traditional district offers a hydrous contribution of 3.42% as an average summer day. And except the post sunset period the most important values are always recorded in this same district with a maximum value of 7% at 21h00. The classification of the remaining samples places the colonial district in the 2nd position, followed by Star Melouk district, then Hay Moudjahidine district and the 500 appartments.

5.4 Comparison between the absolute deviations of air velocities

In the fabrics where the built framework is very dense, the air velocity is altered. The first three samples present the most important reductions, but of more significant part in the district of Mcid where the effect of the density is combined with that of the palm plantation.

The positive values of the absolute deviations indicate contrasting thermal effects from one place to the other, which cause a displacement of air masses from high pressure fresh zones - towards low pressure hot zones - of -. (Hamel & al, 2000)

6 INTERPRETATION OF THE RESULTS

6.1 *Effect of urban density on air temperature and radiant temperature*

The first remark which one could draw from the study of the achieved results is that the city remains hotter than its non urbanised immediate environment (the weather station). This study called into question certain assumptions saying that in arid areas, the city is fresher than its immediate environment. For the summer season, the average values indicate a difference which can reach 3.54°C for air temperatures (with the 5th sample at 09h00) and 12.80°C for the radiant temperatures (to the 4th sample at midday). However the maximum values show a difference reaching 4.70°C for air temperatures (the 4th sample at 09h00), and 14.3°C for the radiant temperatures (with the same district at midday). The results of the spring season underline of advantage these differences, with for the average temperature of the air a difference in 5.25°C (to the 4th sample with 09h00), and a maximum difference of 7.1°C, within the same district (It should be noticed that a 2°C difference represents a climatic change equivalent similar to a 200 km displacement towards the south, at the same altitude). One thus identifies an effect called urban heating effect, appearing in a difference between the temperatures observed in the city and the value recorded in the weather station. This phenomenon constitutes the principal manifestation of the modifications produced in the radiative and energy balance.

In addition this reheating is not similar in all the samples. The handling of the density of the built framework influences it enormously. The outcome given by the comparative analysis of the results gives rise to a progression of the average daily air and radiant temperatures labourers of the which goes hand in hand with density reduction; as well as a progression of the average temperatures of the crossings of the period post sunrise until before its sunset.

For the average daily air temperatures, in summer season the weakest variation is that of the 1st sample, followed by the 2nd and 3rd sample, then the 4th sample, and finally the 5th sample. And it is the same pattern in the spring, for the first four samples.

With regard to the radiant average temperatures, the weakest variation is noted in the 2nd sample of the first category (very dense fabric), then there are the two types of the 2nd category (dense fabric), and finally the type of the 3rd category (loose fabric).

Nevertheless it is necessary to acknowledge that the 1st sample constitutes a particular case, because although the urban density is high, but the MRT remains more important compared to the case of the Colonial District. In fact, it appears that this characteristic is due to the recent tarring of the Mcid streets ; as to the difference between the protection offered by the foliar mass in these two samples, which offers more important shade in the district (an important foliar mass of the groupings of trees), compared with Mcid district (palm trees).

It was as noted that the average of the air and radiant temperatures, in some moments of the day, in season of summer, are more important in the 4th sample as in the 5th, although the urban density is more important. It seems here, that the choice of the points of measurement was determining, because in Hay El Moudjahidine district, they are for most of the cases balanced by three active surfaces (ground and two frontages). Which is not the case with the 500 residences, where the separative distance between a point of measurement and the frontages which limit space is important. What occasioned that the influence of the radiative reflexions is accentuated in Hay El Moudjahidine and is masked with the 500 residences. Another particularity was detected, it is the recourse to the means of air-conditioning in the 4th and the 5th sample, which appears that it had its contribution in the rise of the variations of the temperatures before the sunrise, because of the accumulated heat released during all the night.

The very dense urban fabrics (Star Melouk, Mcid) by their low heat capacity due to an increased urban reflectance and to a deteriorated thermal capacity, starts to cool down before even the sunset; this made so that towards the rising of the sun of the following day the terrestrial radiative losses in these districts cease. When the solar radiation is intense, the effect of the evapotranspiration and materials become less sensitive, and it is the urban density which presides over microclimatic conditions on an urban fabric scale.

Thus we can say starting from these conclusions that the first two samples: Mcid and Star Melouk constitute optimal cases from the point of view of microclimatic control, for this experimentation. The reduction of the reheating is due, in the first case, to the effect of the density and the insertion of the frame within the palm plantation; however in the second, it is with the frame alone due to its strong compactness. It comes out from that, f one manages to combine between the strong density and compactness of a planar frame and the suitable integration of the vegetable element, one will be able to obtain a perfect case from the point of view: of the urban heating effect attenuation, and the correction of the adverse effects on the microclimate of the city. (Hamel, 2005)

6.2 *Effect of urban density on the relative moisture*

The effect of the urban density on the relative humidity is also different according to the season as well as the moment from the day. Its effect cannot be dissociated from that of the air temperatures. Generally, in the densest districts (Mcid and Star Melouk) and those containing the important parks (colonial District), relative humidity is more important than at the station. In low density districts (Hay El Moujahideen, 500 apartments) the relative humidity knows a reduction which can reach 9% in summer (with the 500 apartments with 09h00) and 15% in spring (in Hay El Moujahidine).

According to the average of the absolute deviations of the relative humidity, the traditional district offers a hydrous contribution of 3.42% as a daily average summer day; and a part from after the sunrise, the most important values are always recorded in this same district with a maximum value of 7% with 21h00, and a difference compared to the other cases which can reach 6%. The classification of the remainder of the samples places the colonial district district in 2nd position followed by Star Melouk, then Hay El Moujahidine and the 500 apartments. For the spring season, the average values are generally lower than the values of the station, but more in the 4th sample. It thus appears that the first sample constitutes the most optimal case as far as humidity gain is concerned, in the summer season, where the need for cooling by humidification is necessary. (Hamel, 2005)

6.3 *Effect of urban density on the air velocity*

Table 3. Percentage of air velocity in each sample, of the value recorded in the weather station, and produced alteration.

Sample	Average Vair (m/s)	Weather station Vair (m/s)	Average Vair (%)	Alteration (%)
M'Cid district	0.64	4.6	13.91	86.09
Star Melouk district	0.43	2.4	14.27	85.73
Colonial district	0.17	2.4	7.17	92.83
Hay El Moudjahidine district	0.87	4.6	18.96	81.04
500 apartments	0.84	10.2	27.80	72.19

The air flow is influenced by the density of urban fabric, green surfaces as well as thermal contrasts from one place to another. In the fabrics where the built framework is very dense the air velocity is faded. The first three samples present the most important reductions, but of more significant part is in the Mcid district where the effect of the density is associated to that of the palm plantation. The effect of the thermal breezes which consists of a displacement of the masses of air from the fresh zone of high pressure, towards the hot zone of low pressure, is perceptible in the Star Melouk district and with the Colonial District before the sunset and with the 500 residences before the sunrise. It thus appears, that the urban heating effect is not without impact on the air circulation. The phenomenon of the thermal breezes constitutes an important aspect of cooling by convection which can be exploited for a better ventilation of the city. In addition the direction of the wind is very fluctuating and depends on the one hand on local winds (speed and direction) and on the other hand of the direction of the network of roadway system. (Hamel, 2005)

7 CONCLUSION

A sustainable urban form is the result of a compromise between the most decisive aspects from a point of view environmental, economic, social, and cultural, with a rational arbitration between them. In the context of the arid areas, the most decisive elements seem to belong to the climatic aspect. The control of the urban climate and the fight against the reheating in the cities of the arid areas with hot and dry climate, can be reached only through the attenuation of the exposure to the solar radiation, the reduction of the temperature of the air, the improvement of the levels of moisture and the conditions of air flow, as well as the control of pollution. These strategies can be carried out by a compact urban design.

In addition, it appears that the compact city responds better to economic, social and cultural constraints. Nevertheless the high density is not an absolute concept, it remains relative, because it is related to many factors, such as the size of the city, the type of layout, the form of the buildings, the parks and opened spaces, etc. As well as functional co-education and processes of intensification and decentralization. (Jenk & al, 2000)

By admitting that the size of the cities of arid areas will be limited - considering the natural environment of the desert unable to support over-populated urban centres- one concludes that the sustainable city in this context, will be a denser city, with more compact forms of the new development, and a thickening of the existing urban surfaces.

We do not tend in any manner, to propose a model of city, and to fall into the temptation to create an idealistic model - as one tends to often think of it -. The suggestion of a compact city is, mainly, to adopt it not like an absolute model, but rather like an abstract concept, which requires to be revalorized and developed, in order to be able to benefit from opportunities a compact urban form can offer, without falling into a passeism. In addition, if the concept of compact city currently answers the environmental concerns (climate, pollution, reheating, etc), it is currently impossible to circumvent that it is re-examined, in the sight of a satisfaction of the evolution of the economic, social and cultural processes, in progress, in order to be able to be combined in adequacy with the sustainable development.

Finally, to build sustainable human establishments for the future, it is necessary initially to re-conceive the existing urban forms, by considering the utility of the multi-field studies, in planning and in urban design, so that they can be sustainable.

REFERENCES

Hamel Khalissa & al. 2005. *la ville compacte: une forme urbaine d'une ville durable en régions arides* (Mémoire de Magistère). Département d'architecture. Université de Biskra.

Cordier, J.P. & al. 1989. Forme, orientation, énergie. In Cahiers pédagogiques, *Thermique et Architecture*. Imprimerie F. Paillart. Abbeville.

Jenks, M & Burgess, R. 2000. *Compact cities, sustainable urban forms for developing countries*. Spon Press. London.

Goyette-Pernot, J. & Compagnon, R. 2003. Climat urbain et énergie. In Actes du séminaire, *Énergie et environnement*. CUEPE, Université de Genève.

One Planet Living Pioneer Project

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ABSTRACT:

The plan includes concentrating the proposed development area into one unit. The team plans to use the receipts from the development as a form of a 'green tax' to fund conservation measures throughout the area eg. forest replanting and restoration, creating closed-off protected areas for vulnerable nesting birds, recovering wetland and other important riverine and coastal habitats.

The plan also proposes to be innovative and ecological in it's development e.g. use of sustainable building materials and solar power. WWF partners BioRegional are helping to integrate effective energy and water efficient designs into the Portuguese plan.

THE MATA DE SESIMBRA / ONE PLANET LIVING PIONEER PROJECT

"The natural environment we treat with such unnecessary ignorance and recklessness was our cradle and nursery, our school, and remains our one and only home … . That is the essence of environmentalism. It is the guiding principle of those devoted to the health of the planet." - Edward O. Wilson, 'The Future of Life'.

PROJECT SUMMARY

The development is part of an overall project that covers an area of 5,300 hectares and brings together sustainable housing, nature conservation, reforestation and ecofriendly transport. Work will begin on the 6,000-house, €1 billion scheme just south of Lisbon during the first quarter of 2006.

The development, which replaces a proposal to build a conventional tourist resort, will be completely powered by renewable energy, dramatically reduce waste to landfill – to just 5 per cent of the Portuguese national average – and use rainwater collection and waste water recycling systems to achieve huge cuts in domestic water consumption and irrigation.

More than half the food served in tourist facilities will come from local resources. The plans include creating a sustainable transport network – featuring for example shared and non-petrol vehicles, and a cycle route encompassing the entire site. The aim is to eliminate the need for private cars the area.

The project includes a 4,800-hectare nature reserve in which habitat corridors, linking surrounding protected areas will create safe havens for vulnerable nesting birds such as the Bonelli´s Eagle. The site will also be home to one of Europe's biggest privately financed forest restoration projects which aims to recreate native indigenous woodland – mainly cork oak and umbrella pine – replacing the existing eucalyptus and non native pine forest.

Figures suggest that over the next 20 years, tourism in the Mediterranean will rise by 50 per cent to an estimated 350 million people visiting the region each year. Conventional, mass tourism has been identified as one of the major threats to the "natural capital" of the Mediterranean region, through high consumption and waste levels, and also direct destruction of natural areas. In a country where tourism represents 10 per cent of national GDP, the alternative model of sustainable tourism being developed as part of the Mata de Sesimbra OPL project if tourism is to go hand in hand with sustainable development.

THE PHILOSOPHY BEHIND "ONE PLANET LIVING"

WWF´s Living Planet Report suggests that if everyone on the planet were to consume natural resources and pollute the environment as we currently do in Europe and North America, we would need between 3 and 5 planets to support us[1].

The challenge that faces us all is: how can people everywhere enjoy a high quality of life, within the carrying capacity of one planet?

One Planet Living must be affordable, for both people and the planet, and it must be attractive to a wide range of people, with divergent cultural backgrounds, living in different parts of the world.

One Planet Living must address the "basket of human need's including housing, clothing, food, healthcare, education, energy, mobility and leisure.

One Planet Living must also be simple. Currently it is too easy for people to make decisions that are unsustainable; One Planet Living means changing the "default" of our daily lifestyle decisions to ones which are sustainable.

WWF International and BioRegional are partners in the UK's largest eco-village, the Beddington Zero Energy Development (BedZED) consisting of 100 homes and workspace for 100 people. BedZED's design is multi-award winning and the site is frequently visited by Housing and Environment Ministers from around the world. BedZED is helping residents to lead a lifestyle which is kinder to the planet, without having to make lifestyle sacrifices.

The effectiveness of the ZED (Zero (fossil) Energy Development) design pioneered by BioRegional can be further increased as the scale of development is increased. This is because shared facilities and infrastructure can start to be addressed too.

The "Mata de Sesimbra" development in Portugal aims to go a significant step further than BedZED by having the 20 year target of having 'zero waste' – but reaching a massive 75% of landfill diversion in the first year. 'Waste' will be utilized for horticulture purposes. The type of recreational activities will be diversified e.g. horse-riding, cultural centres, whilst facilities such as the golf course will be fed only by treated waste water and low/no use of pesticides.

APPLYING THE ONE PLANET LIVING APPROACH

"One Planet Living" is an initiative designed to help people, businesses and local and national authorities live and work within the natural limits of our One Planet.

It presents an integrated strategy that helps make "sustainable development" a reality, by setting targets for the following 10 principles:

1. Zero Carbon
2. Zero Waste
3. Sustainable Transport
4. Local and Sustainable Materials
5. Local and Sustainable Food
6. Sustainable Water
7. Natural Habitats and Wildlife
8. Culture and Heritage
9. Quality and Fair Trade
10. Health and Happiness

PUTTING ONE PLANET LIVING AND SUSTAINABLE DEVELOPMENT INTO PRACTICE

In order to ensure the project meets the demanding aspirations and objectives of the One Planet Living initiative, a Sustainable Action Plan based on the 10 principles has been developed AND INDEPENDENTLY APPROVED. From this Plan, a series of Specific Sustainability Business Plans, and a Sustainability Action Review process, have been developed.

The Mata de Sesimbra OPL "Pioneer Project" sustainability action plan includes the following specific actions plans:

USE OF SUSTAINABLE BUILDING MATERIALS

- sustainable materials and construction methods
- exclusion of toxic materials
- highest possible use of reclaimed, recycled and certified materials (eg. FSC) and products (eg. Fair Trade)

ZERO CARBON PLAN

- green transport system
- renewable energy and energy efficiency
- renaturalisation of surrounding environment
- bio-climatic architecture and high thermal performance of buildings
- installation and use of A-rated appliances only

ZERO WASTE PLAN

- reduction, reuse and recycling strategies
- composting of organic waste
- reduce landfill
- use of recycled goods

RENEWABLE ENERGY AND ENERGY EFFICIENCY

- energy conservation through design
- use of solar energy

USE OF LOCAL RESOURCES

- Cut food miles pollution, and revive traditional local industries and crafts
- ensure minimum percentage of goods and services come from within 50 km range

SUSTAINABLE TRANSPORT PLAN

- reduce car use in urbanized areas
- promotion of cycling and walking
- provision of public and shared transport options eg. Car club
- promote alternative tourist transport eg. train
- support WWF campaigns eg. Aviation taxes

CONSERVATION PLAN FOR FAUNA AND FLORA

- natural habitat restoration eg. Replace exotic species with native woodland and shrubs
- increase overall biodiversity
- create new local habitat corridors, and link to regional corridors
- conservation plans and funds for threatened species and protected areas in the region

WATER CONSERVATION PLAN

- reduce domestic water consumption rates
- achieve major savings in water use for leisure eg. garden irrigation, swimming pools and golf courses

QUALITY OF LIFE PLAN

- Promoting social identity and community-building measures
- Showing how it is possible for social and ecological development to support sustainable local economic growth

HERITAGE PLAN

- preserve and promote the area's cultural, natural and historical values and environmental assets
- provide environmental awareness-raising, training, and promoting the philosophy of 'One Planet Living'

<u>These actions plans have been developed into a programme with specific set targets that must be met and independently verified.</u>

SUSTAINABLE MATERIALS

- Min. 50% use of recycled materials eg. Cement
- Min. 90% elimination of toxic materials
- Min. 50% of materials from 50km radius
- Min. 30% reduction in embodied CO_2 in construction, transport and use of materials

ZERO CARBON

- Reduce energy use of lights and appliances by 40% by installation of A-rated appliances and designing buildings to maximise daylight
- Reduce ventilation by 44% by use of natural wind-driven solutions
- Reduce water heating energy use by 60% through use of flow restrictors, spray taps, efficient shower fittings, and use of solar water heating
- Reduce space heat/cooling by 95% by use of passive solar heat, glazing and insulation, and south-facing facades and shading solutions

ZERO WASTE

- Reduce waste production by 25% by elimination and reuse of food packaging, promoting reusable packaging and discriminate against disposable products
- Ensure minimum 25% of waste is recycled, and 0% incinerated
- Compost over 90% of organic waste
- Reduce landfill to 5% of national average

RENEWABLE ENERGY/EFFICIENCY

- Achieve 100% renewable, non-fossil energy production by including photo-voltaics in architectural design, include solar thermal design, use small-scale bio-mass heating, and water ponds for space cool system

LOCAL RESOURCES

- Minimum 25% of food consumed within the development to have come from 50km radius, by organising network of local product and service suppliers
- Minimum 15% of key services provided locally, by offering preferential contracts for purchasing and hiring of local services, and supporting the development of those not currently available
- Employ 6,000 people from local area in order to reduce unemployment, and develop skills enhancement programmes
- SUSTAINABLE TRANSPORT
- Reduce car use to 0% in urbanised areas through hard barriers and promoting alternatives such as walking and cycling
- Implement €100 million public transport and road network
- Increase average number of passengers per car to 3-per-vehicle through a car-sharing scheme

FAUNA & FLORA CONSERVATION

- Convert existing degraded monoculture forest, consisting 90% of exotic eucalyptus and pine, to native oak woodlands
- Implement €20 million conservation strategy
- Create local habitat corridors, and connect to regional ones; and conserve and increase sensitive wetlands and dunes
- Conserve and improve conservation status of target and vulnerable species, such as Bonelli's Eagle; and protect and regenerate pockets of biodiversity eg. Cork forest and Mediterranean maquis, and important habitats (eg. Bird of prey nesting sites) from disturbance

WATER CONSERVATION

- Reduce overall water consumption by 25% by use of greywater recycling, low-flush systems, low-flow taps, and rainwater catchment
- Apply EGA Ecology Unit/Audobon Society rules to achieve major savings in sports and leisure-related water consumption

QUALITY OF LIFE PLAN

- Apply environmental quality indicators, such as air and noise pollution
- Enact €100 million programme of sports, leisure, cultural and educational facilities
- Minimum area of social facilities, open spaces and green areas per capita

- Achieve positive values for attitudes to facilities and the community, and negative values for stress levels, through communication and participation programmes

HERITAGE PLAN

- Preservation and educational programmes, and supported programmes to promote local heritage through strategy to promote natural, cultural and historic values
- Advertising of local heritage, facilities, products eg. Crafts
- Promote OPL awareness through One Planet Living Centre

HOW DOES ONE PLANET LIVING DEFINE SUSTAINABLE LIVING?

Ecological footprinting analysis is an accounting tool that represents the environment impacts of a process or person's lifestyle in terms of the area required to produce a particular natural resource or to absorb waste from consumption. It is a measure of the area of biologically productive land, sea and freshwater that is required to produce a good or service, or meet the needs of a person or population. It compares this area with the actual available area on earth and informs us whether we are living within the earth's regenerative capacity.

A person's ecological footprint is made up the footprints of all their activities, products consumed and waste produced. It includes the area of forest required to sequester the CO2 emissions attributed to that person, and a share of the area taken up by infrastructure and the production of goods and services. A person's energy consumption has an ecological footprint, as do their food consumption, transport, work activities and leisure activities.

Ecological Footprinting figures in WWF´s Living Planet Report 2002, inform us that it takes a biologically productive area around 5.35 global hectares to support each person in Europe, whereas the actual available productive area on Earth is 1.9 global hectares per person[3]. Hence, it can be concluded that if everyone on the planet consumed as much as the average person in Europe, we would need tree planets to support us.

This analysis suggests that Europe needs to reduce its consumption of fossil fuels and virgin materials by two-thirds to be environmentally sustainable within a concept of living within a fair share of the Earth's resources. To achieve this reduction in consumption we need to develop sustainable ways of living.

The implications of not achieving this two-thirds reduction are substantial and bleak for the future of planet earth and its inhabitants. We will not be able to live sustainably on a small planet with divisions between rich and poor, where the rich are destroying the planet through over consumption and the poor through desperation. If we do not change the way we live, we will continue to cause environmental damage and store-up long term social, economic and health consequences.

HOW DOES ONE PLANET LIVING DEFINE SUSTAINABLE DEVELOPMENT?

A wider definition of sustainability covers more than environment impact. It is frequently defined in terms of the "triple bottom line" comprising social, environmental and economic sustainability. For our future developments and communities to be truly sustainable, we must address social amenity, creating sustainable communities with spaces people want to live and work in.

Developments must also offer financially sustainable solutions that are viable within a market economy.

The environmental, social and financial issues surrounding sustainable development are particularly closely inter-linked in the housing sector. Ensuring access to appropriate, efficient and safe homes plays an important role in community well-being and regeneration, as does ensuring that such homes are affordable to build, buy and run, in addition to being designed to tackle issues such as fuel poverty.

IMPORTANCE OF LIFESTYLES

Addressing the environmental sustainability of the construction and occupation of buildings is of great importance if we accepted that we need to meet a two-thirds ecological footprint reduction target. However, in creating sustainable homes we should not only to consider the houses themselves, but also their relationship to the infrastructure that supports them, e.g. transport, work, leisure, food supply and waste recycling.

Carbon Dioxide emissions have a major impact on our ecological footprints, and the area of forest required to sequester CO2 emissions is included in our total ecological footprint. As approximately two-thirds of our individual CO2 emissions in Europe are attributable to our lifestyle more generally, including food and transport4, it is desirable that a future eco-rating label for homes should assess more than energy efficiency alone, if it is to represent a more accurate picture of sustainability. For example, is an energy efficient home that can only be accessed by a 20 mile car journey really sustainable?

Environmental analysis, including Ecological Footprint assessment, highlights the fact that the majority of our environmental impacts as consumers, and hence potential savings, are attributable to lifestyle decisions and not the materials used in the products themselves. This logic can be applied to homes as products, and although houses builders cannot control how the consumer uses their product and whether their use patterns are sustainable, the way a product is designed can certainly encourage a particular lifestyle or behavior.

CONCLUSION: THE CHALLENGE

The One Planet Living Communities program is abut choices - choices that allow us to close the loop. Choices and challenges we all face if we want to live a high quality of life within the resources of our planet. Everybody is committed to the need for change, but do they want to change?

One Planet Living is an opportunity to design developments that will enhance a sense of place for all that live there, and to promote social and economic interaction. The creation of these communities implies responsible leadership not only to deliver an attractive project, perhaps an outstanding one, but ensure that the management of the community is done in an integrated way.

The greatest impacts occur during the life cycle of the communities and it's during this time that we must offer the choices, making easier to make responsible and sustainable choices. We can establish goals to minimize the use of renewable resources, the production of waste and emissions, efficient use of energy, but we also have to ensure that will be social interaction, local economic activity and provide financial sustainability of all activities because if the "project" we create is too expensive it will not be a good example and we will not achieve a high quality of life within the resources of our planet.

Reflecting about the emergence of sustainable urban communities – a social ecological point of view

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ABSTRACT:

Sustainable urban communities are defined by a set of well organized? Sub-systems, natural and human, functioning altogether in a systemic way. In nowadays Sustainability represents the main goal of societies that aim to have a future, by learning from past errors and not jeopardising the opportunities that the present still offer.

The authors argue that it is dangerous not only to consider the urban ecological issues as a fashion, but also to think them on a purely environmental preservation perspective. Instead, urban communities should be understood as living realities, where the built environment, the natural conditions, the social activity – including investment decisions - and the people choices' play an important role.

The authors suggest that the concept of ecological complexity? Is useful to understand how an urban place works. Additionally, the concept of ecological complexity could also be helpful to design an urban change evaluation programme, which the authors consider absolutely vital.

1 REFLECTING ABOUT THE EMERGENCE OF SUSTAINABLE URBAN COMMUNITIES – A SOCIAL POINT OF VIEW

This communication presents a social ecological perspective about sustainability in the context of urban planning and building construction. The social ecological perspective states that the emergence of sustainable urban communities is crucial to the survival of the social and environmental world we have gained which is presently characterized by a deep ecological crisis and the lack of sustainable solutions. Moreover, the social ecological perspective also posits that the promotion of sustainability has to imply a discussion about the environmental, technical and scientific ethics and the mechanisms of the citizens' democratic participation, to ensure that the world of tomorrow will be economically more balanced, socially less unfair and much more feasible, Thus, sustainability could be understood as a political value, that influences the strength of the policies to change the places we leave on and the societies we belong to.

The role of technology to achieve these goals is unique. However, sustainability can not be limited to a technical solution or a technical intervention. Indeed, it is necessary to also consider the consequences of territorial changes. In fact, the main issue is strengthening environmental ethics which appeals to the public suffrage of public works. Additionally, we suggest that decisions regarding infrastructure and human construction do not raise technical problems, but instead they are a result of political processes. Thus, the study of political decision-making processes is indeed key element for the analysis of how societies can achieve sustainability.

We also propose that public participation is another important topic regarding sustainability. Buildings' sustainability integrates several dimensions, namely natural resources, social equity and economical development. Thus, a strategic planning, that fits to the reality, can constitute an essential tool to achieve sustainability. Technical solutions toward indoor comfort, urban mobility and communications as well as generalized access to environmental data must be taken into account by users. That is, decision-making processes must consider the public participation component since its starting phases.

Built environment, human mobility and sociabilities are important issues in what regards to sustainability. In this paper, we emphasize the role that public participation (Munier, 2006) and environmental ethics play on the debate regarding the social consequences of technical applications in a time shaped by ecological scarcity (Soromenho-Marques, 2003). In Portugal, like where else, this topic is particularly relevant, especially because we are still building basic infrastructures (airports, roadways, and railways) or rehabilitating older ones.

Ecological scarcity challenges the discussion about the division between human culture and nature that architecture reproduced in built environments (Rodeia 2006). Inner city inhabitants lost the notion of environmental dependencies. The types of construction and domestic comfort are centred in technological and legal aspects, and often subordinated to market trends. Characterizing populations, attitudes and demands, as well as analyzing the way public participation integrates decision-making processes, is demanding to define a methodology to assess urban sustainability, even when implemented actions trigger unfavourable public opinion and/or public dislike. Urban sustainability also influences population's feelings of insecurity and the way individuals participate in the decision-making processes. Thus, the major question is to preserve a strategic alliance between technology and citizenship, which implies an interdisciplinary discussion (see Figure 1).

In fact, what is the purpose of adequate technical decisions that do not take into account the concept of ecological complex (see above) ? A sustainable construction project must consider dimensions like public participation and community safety. Also, methodologies that account for the processes of social impact assessment (Craveiro, 2004) are useful to urban sustainability analysis if we believe that built environment has consequences on human communities' safety and also on its relation with technical and political decisions. In fact, a set of social indicators must be considered regarding the social characterization of populations, its habits and demand expectations, attitudes toward the environment, sense of insecurity or ways of public participation which, among other aspects, already integrate processes of social impact assessment.

Altogether, urban planning and building construction involve an array of practitioners and users, each one confronted with specific challenges that are vital to face the contemporary social and environmental challenges. Certainly, all of them have a sense that sustainability is a good thing (and that being unsustainable is a bad thing), but will they know it when they see it? Do they share a common view about sustainability and underlying principles? A common criticism is that different meanings and definitions have been attached to the term sustainability over the years. Based on a critical overview of this multiplicity of meanings, we propose what we call an operative conception of sustainability.

This operational conception of sustainability takes into account the already identified aspects involving social impacts evaluation, highlighting the importance of water and energy demands and solid waste production (Vasconcelos Paiva et al., 2006), not only in the construction phase but also in the using and occupation phases. Sustainability must be deeply discussed in order to undo the easy achieved consensus regarding its own definition (Redclift, 1992). There is no urban sustainability without public participation and without an alliance between technology and the exercise of citizenship. This led us to the analysis of the current environmental legislation and its application in the different regional contexts. It is also important to take into account the population level of environmental awareness and its relation with education levels, urbanity and public participation. Urban built environment is related to inner city inhabitants and ultimately urban built environment depends on the uses that inner city inhabitants do toward population's well-being. The issue here is to know if the environmental legislation can be adopted in social and regional disadvantaged areas where the receptiveness of public policies can be more difficult. We refer to less developed countries, technologically speaking, where traditional communities react awkwardly to political regulation. This discussion refers to the political institutions competences to promote sustainability. Finally, It is also important to state that one of the more demanding challenges is to achieve public receptiveness, because institutions might have to deal with few gains if individual action do not act in a collective way.

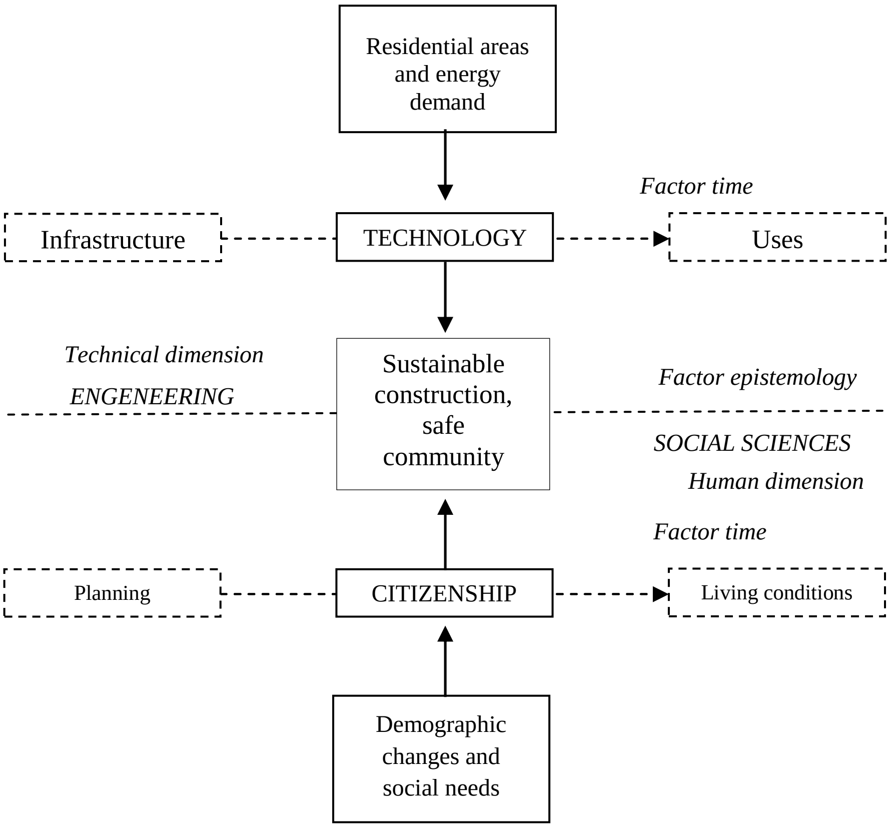

Figure 1 – Sustainable construction: human and technical dimensions

The application of the concept of sustainability to cities and urban settlements faces particular difficulties. If it is rather consensual that current patterns and forms of urban development are not long-term sustainable, which concept of sustainability and idea of sustainable urban community could serve as basis for the systematic identification? What are the changes in the ways people habit a city and use its common and private spaces and resources that could interfere with the ideal-type of sustainability? In fact, we have also to consider that the way people live interferes, obviously, with the environmental quality. Are we all conscious of this?

Currently, several common features related to the mean of sustainable urban communities have been referred to in the literature: the more efficient use of land and space; the emphasis on the redevelopment of underutilized urban areas; turning communities more green and more amenable to walking; the investment on renewable energies and low pollution; the investment on public transportation and reduction of dependency on individual private transportation; and, more recently, enhancing resilience of communities to natural disasters. Are these challenges common to any kind of urban settlements in the world or do they reflect the worries of developed societies? Do the cities and settlements of the developing world pose specific challenges? Could we imagine a sustainable social an urban development in a world split between rich and poor societies, without a strong going back in what regards our cultural and political achievements?

The social ecological perspective aims to take into account all the questions above mentioned, and thus contributing to the emergence of (real) sustainable urban communities. In order to guarantee that this social ecological perspective is effective and socially useful, it is crucial that this approach is integrated in an urban change evaluation programme, capturing the significant changes in the social factors (population, technology, culture, social structure, personality), as well as capturing the relations between those factors and the different existing environments (social, modified, natural and built). That is, we intent to give answers and promote solutions rather than stay in the diagnosis stage.

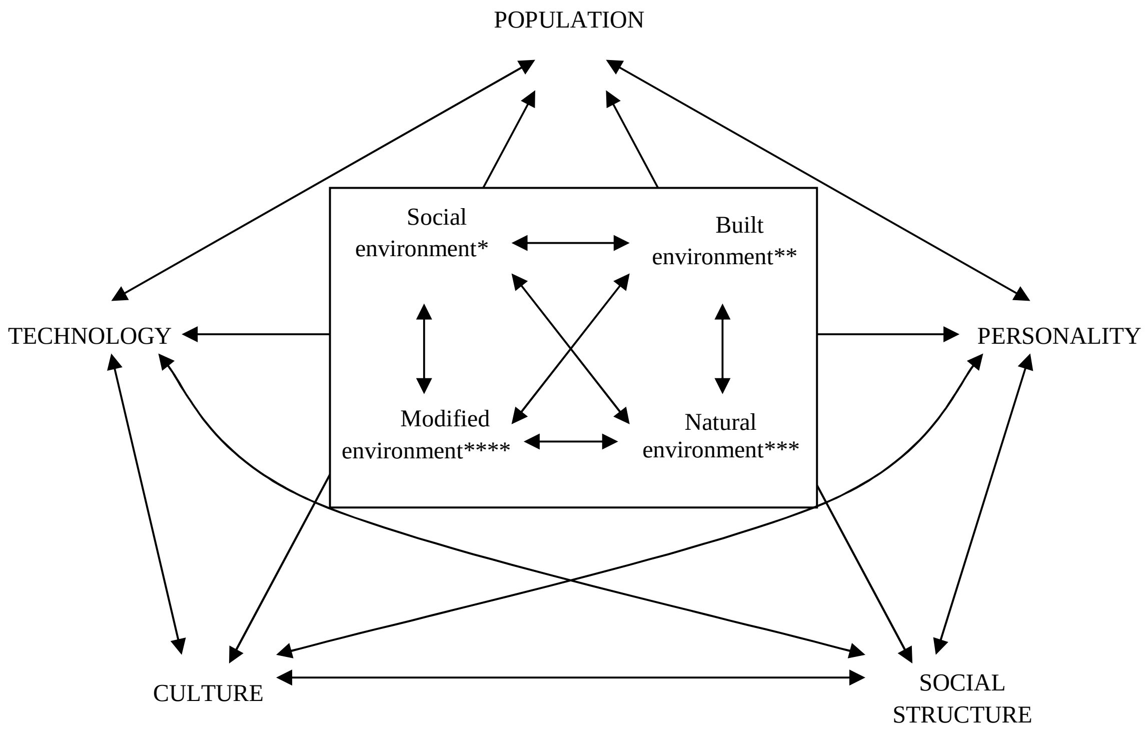

Figure 2 – Ecological complex – revisited version (Catton e Dunlap, 1978)
Source: adapted from Martell, 1994.

Legend:

- * Social relations
- ** Houses, cities, roads, dams, etc.
- *** Environmental conditions not modified by the human action (e.g. natural climate conditions of a region)
- **** Environmental conditions changed by human intervention (e.g. atmospheric contamination, land drainage, swamp drainage, ground levelling, etc.)

The urban change evaluation programme should an effective battery of urban development indicators. With those indicators, local governments and stakeholders could know the critical issues they face, the undesirable changes occurring, and the impact of the carried on policies. Moreover, they should be aware of the priority decisions (investments, legislation, organizational procedures) they have to take.

Last, but not least, if the ecological complex means the search for a dynamic balance between the social factors identified at the urban milieu, then this dynamic balance could be the programmatic target of social change. The sustainable urban communities of tomorrow should benefit from the procedures we put in action today.

Social players (City Hall, decision-makers, politicians, technical staff, investors, residents, other stakeholders) could benefit from a strategic perspective that sees sustainability as a societal goal. This should mean that the urban and social development could be able to respond to social needs of the present, using the best scientific and technical knowledge available – without disrespecting the good traditions and the good practices of the past -, not jeopardising the needs of future generations and achieving the balance between the economic interests, social aims, environmental challenges and technological opportunities, as well as the incorporation, above all, of a set of ethical values.

References:

Bullivant, L., 2005. Interview with Ellen Van Loon. In The Plan, Architecture & Techologies in Detail, n.º 10: 35. Bologna: The Plan, Art & Architecture Editions.

Craveiro, J. L., 2004. A Avaliação de Impacte Ambiental: a dimensão social. Lisboa: Laboratório Nacional de Engenharia Civil.

Martell, L., 1994. Ecology and Society – an introduction. Cambridge: Polity Press.

Munier, N., 2006. Characteristics and Analysis of Urban Sustainable Systems. In Munier, N., Handbook on Urban Sustainable: 35-88. Dordrecht: Springer.

Redclift, M., 1992. Sustainable Development, Exploring the Contradictions. London: Routledge.

Rodeia, J. B., 2006. Le temps du monde fini commence! In Jornal Arquitectos, n.º 223: 18-19. Lisboa: Ed. Ordem dos Arquitectos.

Soromenho-Marques, V., 2003. Crise Ambiental e Condição Humana. In Beckert, C. (Coord.), Ética Ambiental; uma ética para o futuro: 35-43. Lisboa: Centro de Filosofia da Universidade de Lisboa.

Vasconcelos Paiva, J., Aguiar, J. & Pinho, A., 2006. Guia Técnico de Reabilitação. Lisboa: Instituto Nacional da Habitação & Laboratório Nacional de Engenharia Civil.

Sustainable Tourism Indicators for the Coastal Places. State of Research

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ABSTRACT: This paper examines the current state of research in sustainable tourism development as it pertains to these indicators toward the sustainability of a tourist destination. A substantial amount of literature exists regarding the problems involved in operationalizing the concepts of sustainable development and tourism. A key objective of Environmental Indicators for Tourism, is to focus on the indicators related to the Materials Flows and Consumption, to facilitate the communication of environmental information between the different decision-makers. The main objective of further research, is to develop this kind of indicators to measure the current state of a system (visitors, residents, consumption) and monitor its evolution in a period, to reduce environmental impacts deriving from the construction sector deriving from the construction sector linked to the tourist activity by the consumption patterns during the building use phase. *Keywords: sustainable tourism, materials flows indicators, coastal destinations.*

1 INTRODUCTION

1.1 *Evolution of the Sustainable Tourism concept and the Sustainability Objectives*

In 1978, the OMT recognizes the importance of the environmental impacts of the tourism and establishes in 1981, the first Environmental Committee. Nevertheless, in the earlier Nineties is when Sustainability is considered for the tourism development. In 1991, in the 41 Congress of the Association the International of Scientific Experts in Tourism (AIEST) (Kaspar, et al, 1991) named "Qualitative Tourism" settles down the complexity del study of the sustainability and tourism. So, the sustainable tourism was described like "a tourism that maintains a balance between the social, economic and ecological needs. The tourism must integrate the economic and recreational activities with the objective to look for the conservation of the natural and cultural values."

A lot of information and contributions from all the scopes (politician, enterprise scientist and) in relation with the tourism and the sustainability have been written since the Earth Summit, in Rio de Janeiro in 1992. The sustainable development is the axis for any economic strategy and in this case for Tourism. Later, World Wildlife Fund (WWF), the Tourism Concern and the European Union, focused on Tourism and sustainable development, reinforcing the importance of the Agenda 21. Thus, in September of 1993 the Agenda 21 application process and Sustainability were at the tourist scope with the Euromediterranean Conference on Tourism and Sustainable Development (Hyeres-Les Palmiers, France), summoned by the OMT and the countries of the Mediterranean Sea.

In 1994, the World-wide Organization del Tourism, published "For the Travel and Tourism Industry. Sustainable Towards environmentally development ", document in which basic principles in relation to tourism and environment are integrated. In the same year (1994), the

OMT published the document "Indicators of Sustainable for Development Tourism Destinations". This one will be the first methodological guide to measure the evolution of the tourist activity in emergent and mature destinies. The World-wide Letter of the Sustainable Tourism or Letter of Lanzarote was the emanated document of the World-wide Conference of Sustainable Tourism made in the Canary Islands in April,1995. It established 18 principles for a world-wide tourism strategy, sustainable development based. The Letter of Lanzarote supposes the definitive meaning of the bows of Sustainability, the conservation and the development of the resources, and the central paper of Tourism for the development of many localities at of the world-wide geography and very particularly of the developed countries less with one varied cultural wealth of flora, fauna, landscapes and elements.

The Conference HABITAT II (Istambul, 1996) was focused on the urban conditions and services which necessary for a worthy house, as a human right. It extends this characteristics to the tourist destinies because of inhabitable surroundings. The Mediterranean Action Plan was elaborated in the Meeting of Malta (1999). The Spanish and Greek delegations displayed a proposal for the sustainable tourism in the Mediterranean Coasts. because this region environmental conditions. The coasts receive to more than 150 million tourists per year with forecasts of 3 percent an annual growth until the 2020. In 1996 a joint Seminary OMT - ETAG was celebrated in Heilderberg on "Tourism and Environment". The OMT, (World-wide Organization of the Tourism) and the ETAG have come together for the first time in a scientific meeting, (European Group of Tourist Action). Positive is that these two organizations have met to treat, from different scopes, one public and the other private one, the sustainable tourism development and its behaviour towards the Environment. Also, the tourist cities and the spaces natural and rural, bewared or not, but considered inexcusably value(Borrell, 2005).

The Calvià Conference in 1997, reinforces the importance of the Agenda 21 application and the active collaboration between the Mediterranean countries, involving to the local authorities, the social agents and organizations, to preserve the natural and built patrimony. It is important that these regions have reactivated their economic and social development in the last 40 years throughout the tourism industry. The civil participation in the planning and management of the tourist resources with the A21 implantation, is the main subject del Congress the International of Sant Feliu de Guixols, denominated "Sustainable Tourism in the Mediterranean", celebrated in Catalonia in 1998 in the frame of the Ulixes 21 project. In May of 1999 the Commission of Sustainable Development of the UN (CSD-7), in his 7ª carried out Session in New York, emphasized the value of the tourism like decisive sector to improve the management of the resources. According to the OMT, in the "for Guide Local Authorities on Sustainable Tourism Development", published in 1999, the sustainable tourist development must satisfy the necessities with the present tourists and those of the vacation destinies residents, while environment is protected and the opportunities for the future are increased.

The development of a sustainable tourism implies the following requirements: The tourist resources (natural, historical, cultural and others) are preserved so that they allow to be used in the future, simultaneously that benefit the present society. The planning and management of the tourist development will be directed to avoid the ecological depredation or social problems in the region in which it will be carried out. The global quality of the tourist region environment is due to preserve and if it is necessary, to improve it. The satisfaction level would be assured to attract and maintain their commercial potential in the time. The tourism will have to benefit to all the members of the society. That is to say, that the tourism must assure its intrinsic sustainability to the time that must be a powerful development tool to fight the poverty and the inequality in the world. To catalyze this industry, to improve the conditions of life in the countries in disadvantage (OMT, 2002).

In the same year (1999) part of the Agreement of Barcelona is ratified to reduce the contamination in the zone of the Mediterranean Sea and to protect and to improve the marine surroundings of that zone. The protocol has special importance that declares like protected zones several natural surroundings of the Spanish Mediterranean and which they are defined in the European Strategy for the Integrated Management of the Coastal Zones of the Mediterranean (ICZM, 2000).

Promoted within the United Nations for the Environment Program (UNEP) and in collaboration with UNESCO and the OMT, in March of 2000, was signed in Berlin, the "Initiative for tour operators towards the Sustainable Tourism development", designed by the own enterprise sector. This is a voluntary initiative opened to all tour operators, for best practices in the environmental management, cradles in the information and interchange of experiences, implantation of new technologies, the accomplishment of environmental audits and the collaboration with the governments, the tourism industry and other agents (Lopez 2001).

In 2001 the International Conference for the Sustainable Tourism in Rimini, Italy, with the European Union Countries participation, was celebrated the "Network of cities for a sustainable tourism". In the Letter of Rimini is relevant the use of Aids for Assessment and Support to the decision and the action, such as: Analysis of the tourist destiny carrying capacity. Instruments of forecast and tourist evaluation like LCA (local and strategic impact of the services and products), the SEIA (Systems of Evaluation of the Environmental Impact). Multidimensional indicators of Sustainability (economic, social and ecological or environmental) to control the permanent and changing tendencies, in the time and the space, the definitive results of the integrated programs and the processes of A21L.

These instruments will have to be based on the participation of all the implied agents to define and to support the actions for the sustainable tourism, with information sustained and scientifically comprehensible for the end users. One sets out to reinforce the activities oriented to sensitize the tourist company, tour operators and the tourists to exert an active roll in the attraction preservation and to guarantee the satisfaction.

It goes mainly directed to the regeneration and management of mature destinies, where the concentration of the tourist supply and the overcrowding are accelerating their declivity (La Carta di Rimini, 2001). In 2001, in Gijón, the Congress was carried out III the International of Arrangement del Territory, promoted by the Department of Urbanism and Arrangement del Territory of the Technical University of Valencia. In its chapter "Development, Tourism and Environment in the Territory Arrangement" is also spoken of the implementation of Instruments and Methods for the territorial arrangement emphasizing the importance of the Indicators of Sustainability and the different methodologies for its development and control, the Ecological Footprint and the territory Carrying Capacity, concluding that the second residences are promotional of non sustainability (Serrano, 2001).

As far as the Sustainable Development in the European scope, in June of 2001 the European Union Strategy for the Sustainable Development is approved during the Summit of Gotemburg, with annual revisions in each Summit of spring, named “Synthesis Information”. This strategy, with about 40 indicators covering the social, economic and environmental dimensions from "sustainable development" or desirable development, tries to be a certain progress measure in the attainment of a greater quality of life for all (fairness principle), with a smaller use and degradation of the natural resources (principles of effectiveness and effectiveness).

Considered the "sustainable development" like a management and programming instrument in the mid term, through Local Agenda 21, the municipalities have caused even a competitiveness between cities and the companies, in reference to the triple social dimension, economic and environmental of a business that aspires to be lasting or sustainable (Jiménez, 2001).

In the homologous document "Spanish Strategy for the Sustainable Development" (EEDS), published in 2002, the Sustainability is remarked as a synonymous of continuity guarantee and permanence in which it talks about at desirable levels of quality of life and relation. One ties in addition, to the capacity of the average one to regenerate and to serve as drain and considers social and institutional variables to which the economic and physical implications are added.

One of the activities that display a more strategic character for the sustainable development is the complex of activities related to the tourism, remarks the EEDS, by its narrow interdependence with the natural and cultural territory, pressure on the environment and resources that is derived from its degree of concentration, the strong entailments with other branches of activity (transport, feeding, construction, PS, etc.) and the high degree of opening. Denunciation that the untenable tendencies in the tourist places of Spain are:

1. Overcrowded beaches
2. Highways and public services Congestion
3. Potable water shortage (Islands and the Mediterranean)
4. Ecosystem degradation Increasing
5. Pressure on the protected territories
6. Disordered occupation of the territory

Before these realities, the face objectives al sustainable development del tourism in Spain, according to the EEDS are:

1. The management integrated of the coastal tourist zones, planning as far as the impact of the tourism on the Territory, use and Resources consumption and its spatial, temporal and motivational concentration.
2. The rationalization of the tourist supply, betting by the quality.
3. Advantage of synergies between the Tourist Activity and the Environment (EEDS, 2001).

In order to elaborate the information required for the planners of the development of the tourist destinies, the Ministry of the Spanish Environment (MMA, 2000) through his Main directorate of Environmental Quality Evaluation, it has developed a Spanish System of Indicators of ecological and as much global the Tourist Sector of scopes social, economic, as. By this route, it is tried to contribute to follow and to evaluate the environmental situation of the Spanish destinies by means of dedicated displays in areas such as the Atmosphere, the Remainders, the Urban Zones and the Natural Resources.

In 2004, the UNWOT presented to this respect, the "Guidebook on Indicators of Sustainable for Development Tourism Destinations" designed to help to identify the key points and the indicators that can help to the planners the management of the tourist sites, of way which they can maintain his attractive and his viability economic, environmental and social. The indicators are defined in this guide, like "measures of the existence and severity of the present tactically important points, coming signals of situations and problems, measures del risk and of the potential necessity of action and serve to identify and to measure the results of our actions. The indicators provide information that are used formally to measure the changes that are of importance for the sustainable development and his management" (UNWOT, 2004).

1.2 *Definitions of sustainable tourism indicators*

Most definitions of sustainable tourism reflected the idea of balancing the needs of the environment, the economy and the local community (i.e. the ‘triple bottom line’ approach). However, relating to the choice of indicators and important aspects to measure in monitoring sustainable tourism, the researchers suggested that these initial responses glossed over a wide spectrum of views; from perspectives that prioritised the economic viability of existing tourism enterprises to those that were more concerned about the impacts of tourism on environmental and social resources in the Mediterranean coasts, the definitions tended to overlook issues of responsibility within and between generations; and few indicators highlighted behavioural change by individuals and organisations. These findings highlight a gap between the rhetoric of sustainable tourism development and diverse views of how to operationalise it.

Indicators are to help measure change in order to make decisions. Thus, indicators need to measure changes that reflect the ‘triple bottom line’ approach that underpins the definition of sustainable tourism. This means that having a shared understanding of sustainable tourism is a pre-requisite before indicators can be selected. Highlighting, what issues the indicators ought to measure and what indicators currently suggested in the Sustainable Tourism Strategy

An indicator is something that points to an issue or condition. Its purpose is to show you how well a system is working. If there is a problem, an indicator can help you determine what direction to take to address the issue. Indicators are as varied as the types of systems they monitor. However, there are certain characteristics that effective indicators have in common:

1. Effective indicators are relevant; they show you something about the system that you need to know.
2. Effective indicators are easy to understand, even by people who are not experts.
3. Effective indicators are reliable; you can trust the information that the indicator is providing.

Lastly, effective indicators are based on accessible data; the information is available or can be gathered while there is still time to act.

Indicators of sustainability are different from traditional indicators of economic, social, and environmental progress. Traditional indicators -such as stockholder profits, asthma rates, and water quality - measure changes in one part of a community as if they were entirely independent of the other parts. Sustainability indicators reflect the reality that the three different segments are very tightly interconnected. (figure 1)

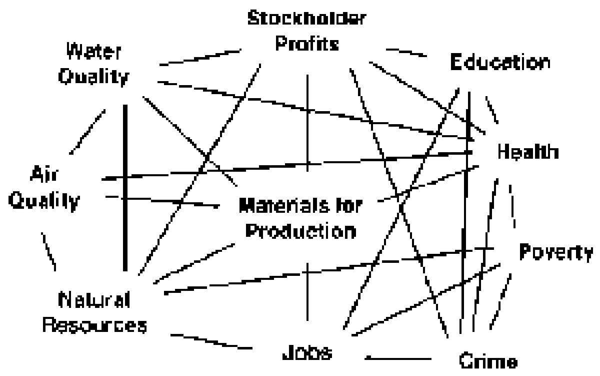

Figure 1. The interconnection of the three dimension of the sustainability

As this figure illustrates, the natural resource base provides the materials for production on which jobs and stockholder profits depend. Jobs affect the poverty rate and the poverty rate is related to crime. Air quality, water quality and materials used for production have an effect on health. They may also have an effect on stockholder profits: if a process requires clean water as an input, cleaning up poor quality water prior to processing is an extra expense, which reduces profits. Likewise, health problems, whether due to general air quality problems or exposure to toxic materials, have an effect on worker productivity and contribute to the rising costs of health insurance.

Sustainability requires this type of integrated view of the world – it requires multidimensional indicators that show the links among a community's economy, environment, and society. For example, the Gross Domestic Product (GDP), a well-publicized traditional indicator, measures the amount of money being spent in a country. It is generally reported as a measure of the country's economic well- being: the more money being spent, the higher the GDP and the better the overall economic well-being is assumed to be. However, because GDP reflects only the amount of economic activity, regardless of the effect of that activity on the community's social and environmental health, GDP can go up when overall community health goes down. For example, when there is a ten-car pileup on the highway, the GDP goes up because of the money spent on medical fees and repair costs. On the other hand, if ten people decide not to buy cars and instead walk to work, their health and wealth may increase but the GDP goes down.

In contrast, a comparable sustainability indicator is the Index of Sustainable Economic Welfare. In order to get a more complete picture of what is economic progress, the ISEW subtracts from the GDP corrections for harmful bases or consequences of economic activity and adds to the GDP corrections for significant activities such as unpaid domestic labour. For instance, the ISEW accounts for air pollution by estimating the cost of damage per ton of five key air pollutants. It accounts for depletion of resources by estimating the cost to replace a barrel of oil equivalent with the same amount of energy from a renewable source. It estimates the cost of climate change due to greenhouse gas emissions per ton of emissions. The cost of ozone depletion is also calculated per ton of ozone depleting substance produced. Additionally, adjustments are made to reflect concern about unequal income distribution. The correction for unpaid domestic labour is based on the average domestic pay rate.

2 LITERATURE REVIEW ON INDICATORS

It was researched a number of peer reviewed and published documents regarding sustainable development frameworks, indicator theory, sustainable tourism management and sustainable tourism indicators. The literature review considers the debates over the definition and operationalization of sustainable tourism and the relationship between sustainable tourism and sustainable development. Fundamentally, sustainable tourism development requires an integrated view of the world that recognizes inter-relationships between environmental, economic and social aspects and how these relationships change over time. As such, sustainable tourism requires an adaptive management approach, whereby monitoring progress is an opportunity for reflection, learning and re-orientating courses of action.

The literature highlights the large number of existing indicator sets but very few evaluations of their implementation. A review of these examples stresses the importance of creating a coherent group as opposed to ad-hoc selection of individual indicators to ensure they provide a clear picture of progress. Selecting indicators often requires a compromise between relevance, scientific validity and measurability. They are always partial and subject to interpretation. The literature suggests that the process of implementing and using indicators is more important than seeking technically perfect individual indicators; and this philosophy underpins our checklist. It also highlights the importance of stakeholder and public consultation in the development of any set of indicators and in their application and interpretation.

2.1 *Indicator frameworks*

A wide variety of indicators exist, but it is hard to know which of these to use and why. Although many indicator sets have been developed, there is very little published evaluation on their effectiveness. The few examples that have applied and evaluated indicator sets for sustainable tourism make a strong case for adopting a framework. A framework guides the choice of inter-related indicators to help target indicators most effectively. Indicators for sustainable tourism in coastal vacation destinations are required to manage changes along the beaches and the natural landscape in order to protect its special qualities. They must cover the key ‘domains’ -or themes-: volume and spread of tourism; visitor satisfaction; tourism enterprise performance and satisfaction; community reaction; and environmental impact. However, they should also measure the multiple dimensions of change in a way that links cause and effect together.

3 SUSTAINABILITY INDICATORS FOR TOURISM AND BUILDING USE

A key objective of the development of Environmental Indicators for Tourism is to facilitate the communication of environmental information between the different decision-makers involved in the course of a tourist destination’s life cycle and to foster the consideration of environmental aspects. The sustainability indicators for buildings, the related to the Materials Flows, by assessing and measuring the consumption patterns. This type of indicators (input-output indicators) (Jensen, 1999) describe flows (of energy, matter and water) through a building in the building’s use phase by measuring (and calculating) the flows that enter the building (input) and the flows that exit the building (output) (Figure 2).

Whether a flow is measured at the input side or at the output side, will depend on pragmatic reasons. In some cases it is easier to ‘take the pulse’ of a flow at the input side, for example in the case of energy, were consumptions are measured as part of the energy billing, while emissions (CO_2, NO_x, SO_2,…) are easier to calculate on the basis of the input than to measure. In other cases it is easier to measure on the output side:

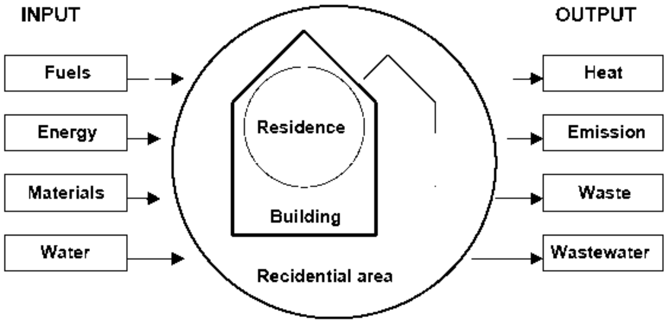

Figure 2. Principle figure showing how matter and energy flow through a (building) or a residential area (Jensen, 1999)

The material flow during the use phase of a building, for example, is measured regularly in connection with the billing for waste disposal and is thus an indicator that already exists, is rather familiar and, accordingly, easier to communicate. Apart from this somewhat pragmatic choice of indicators, the input-output concept draws attention to the fact that *'[…] environmental figures, in the form of materials and energy, cannot leave a system (output), unless materials and energy have already been brought into the system (input). Nothing is lost in the process. […] Our statement of accounts reflects how a residence or residential area forms part of local and global material and energy flows.'(Jensen, 1999.)*

In the form of 'Green accounting' (Jensen, 1999) input-output indicators are an established system for environmental monitoring in the *use phase* of a building. Even though the use phase is not within the scope of this study, input- output indicators are relevant, because the flows monitored by them constitute a major contribution to the environmental impact of a building throughout its life cycle.

3.1 *Indicators derived from environmental accounting*

Environmental indicators are also derived from the broader area of environmental accounting, in both physical and monetary terms. The OECD work focuses, on material flow accounts as a tool for monitoring the efficiency and productivity of material resource use, as well as on expenditure for pollution abatement and control and other environmental measures. Work is also done on the use of accounting frameworks as a tool for sustainable development statistics.

The WTO (UNWOT, 2004) has developed a suggested short-list of key baseline issues and baseline indicators, and more specific indicators for application at different destinations.

3.2 *Baseline Issues and Indicators*

Table 1. Baseline issues and indicators

Energy management	1. Per capita consumption of energy from all sources (overall, and by tourist sector- per person day) 2. % businesses participating in energy conservation programs, or applying energy saving policy and techniques 3. % of energy consumption from renewable resources (at destinations, establishments)
Water availability and conservation	1. Water use (total volume consumed and litres per tourist per day) 2. Water saving (% reduced, recaptured or recycled)
Drinking water quality	1. % of tourism establishments with water treated to international potable standards 2. Frequency of water-borne diseases: number / % of visitors reporting water-borne illnesses during their stay

Sewage treatment (waste water management)	1. % of sewage from site receiving treatment (to primary, secondary and tertiary levels) 2. % of tourism establishments (or accommodation) on treatment system(s)
Solid waste management	1. Waste volume produced by the destination (tonnes) by month 2. Volume of waste recycled (m3) / Total volume of waste (m3) (specify by different types) 3. Quantity of waste strewn in public areas (litter counts)
Development control	1. Existence of a land use or development planning process, including tourism 2. % of area subject to control (density, design, etc)
Controlling use intensity	1. Total number of tourist arrivals 2. Number of tourists per square metre of the site (per square 3. kilometre of the destination)-mean number/peak period average

4 CONCLUSION

The background of the further research is to develop a tool of aid (using basic and linked sustainability and material flows indicators) for planning the sustainable development of the tourist destinations in the Mediterranean region. Because the significant environmental impacts deriving from the construction sector linked to the tourist activity by the consumption patterns.

The various environmentally relevant aspects of a building in its entire life cycle and the relationships between the tourist behavior, are summed up in a limited number of indicators. These serve to formulate environmental requirements to buildings or groups of buildings and to evaluate existing buildings and alternative solutions for new houses. These indicators allow measure the current state of a system (visitors, residents, consumption) and monitor its evolution in a period, in order to plan the actions to achieve the sustainability goals for a coastal destination and the community (people) settled on.

5 REFERENCES

Borrell M., M.L., 2005, Turismo, Medio Ambiente y Desarrollo Sostenible. IUCA-UCM (eds.), *Observatorio Medioambiental* ISSN: 1139-1987, 2005, núm. 8 305-330, Madrid.

Ministerio de Medioambiente, (2001), Estrategia Española de Desarrollo Sostenible(EEDS), MMA (ed.), Madrid.

Jensen, M., 1999, Ecological Building: Or Just Environmental Sound Planning. Arkitektur DK (7): *Architecture. Journal* 353-367). Denmark.

Jiménez B., D., 2001 La Estrategia de Desarrollo Sostenible de la Union Europea en el Contexto Global: De Rio A Johannesburgo. *Proceedings del IV Congreso Nacional de Periodismo Ambiental, Madrid 21-22 noviembre 2001*. Madrid

Kaspar Dr. C, et al., 1991, Quality Tourism: Concept of a Sustainable Tourism Development, *Harmonizing Economical, Social and Ecological Interests*. St-GAl, AIEST, 1991, Vol. 33 of AIEST publications.

La Carta di Rimini, 2001, *Conferenza Internazionale per il turismo sostenibile,* Rimini, Italia.

OCDE, 1993, *Environmental Indicators for Environmental performance reviews,* París, Francia.

OMT, 2002, Turismo en beneficio específico de los pobres, en *Turismo y atenuación de la pobreza.* Madrid

Serrano R., A., 2001, *III Congreso Internacional De Ordenación Del Territorio, Política Regional, Urbanismo Y Medio Ambiente*, Gijón.

UNWOT, 2004, *Guidebook on Indicators of Sustainable Development for Tourism Destinations*, pag. 8. Madrid.

Sustainability and Human Comfort at urban level: Evaluation and Design Guidelines

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ABSTRACT: The transfer of the theoretical knowledge on urban climate and microclimate toward operational design guidelines is a critical issue for reaching sustainability for both cities and buildings. The present paper underlines the benefits of a "green" methodology evolving from urban planning phases to architectural design of urban spaces. It seeks to answer the following questions: At which levels of urban planning and urban design should the climate (i.e. natural energy) be integrated, and in which form? What is the contribution of urban geometry toward the development of thermal comfort conditions outdoors for the pedestrians? What are the most decisive design aspects to consider for meeting this comfort while keeping the best conditions for implementing sustainable buildings?
Findings from personal studies are summarized including numerical results and on-site measurements on outdoor thermal comfort methods and on the dependence of comfort upon the urban structure. Street design recommendations are outlined, supported by a number of examples in order to illustrate their applicability. The most decisive urban describers on human outdoor comfort include the vertical street profile, solar orientation and further design details of the façades and complementary arrangements of the pedestrian areas.

1 PURPOSE OF THE PAPER

The present paper focuses on design guidelines of a thermally comfortable urban street, illustrated by a few examples to show their applicability. Indeed, the street appears as the interface of urban and architectural scales, as it consists on "shared" active facets between the building envelope and the open urban canopy. Designing the street is, hence, a key issue in a global approach for an environmental urban design (Table 1, see also Ali-Toudert 2000, Ali-Toudert and Bensalem 2001). The shape of the street canyon has been reported to influence both outdoor and indoor environments, i.e. the potential for passive solar gains inside and outside the buildings, the permeability to wind flow for internal and urban ventilation, the urban absorption versus reflectance of radiation as well as the potential for cooling of the whole system By implication, the street affects the thermal sensation of people as well as the global energy consumption of urban buildings. The strategic importance of the street is also attributable to its function: the street network of an urban entity has, from a design point of view, a structural role and accounts for the main support for mobility, urban activity, social life, and even reflects cultural specificities (e.g. Mounghtin 2003)
The guidelines discussed here are based on a study which dealt with outdoor thermal comfort in dependence upon street geometry under summertime conditions (Ali-Toudert 2005). The street properties investigated in that study included the aspect ratio H/W, street orientation and a num-

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ber of details, i.e. the use of galleries, rows of trees, and overhanging façades. The full results are available in (Ali-Toudert et al 2005, Ali-Toudert and Mayer 2006, Ali-Toudert and Mayer 2007a, Ali-Toudert and Mayer 2007b). So, the present paper does not intent to duplicate them, and the reader is advised to refer to them when necessary.

Table 1: A conceptualized climatic-conscious urban design methodology (Ali-Toudert and Bensalem 2001)

Concept	Objectives		Indicators	Observations
Openness to the sky	Solar and energetic control	Solar access	Street profile H/W Orientation / Sun	- The depth of a street canyon H/W depends on the solar orientation: E-W allows better penetration of the solar radiation in the canyon volume. N-S streets are more or less exposed around noon depending on H/W. - The choice of a symmetrical or asymmetrical street profile depends on the orientation / sun. - Distinction between street level and building level according to indoor or outdoor issues.
		Nocturnal cooling	street profile H/W	
Urban reflectance		Reflection of the solar radiation	Plan density (roof surface / total surface) H/W (secondary)	- The higher the plan density the larger the urban reflectance, e.g. the compact desert cities. - The street profile has a secondary effect/ Deep streets catch more irradiation, and hence heat.
Urban porosity	Wind control	Urban ventilation (outdoors) Dilution of pollutants	Plan density Spacing between buildings (H/W, H/L) Wind incidence angle	- Large spacing between buildings promotes urban ventilation. - The transversal H/W (perpendicular incidence) is decisive in the flow regime: isolated, interfering or skimming flow. - Oblique direction improves the wind flow in the urban fabric and offers the best potential for indoor ventilation (high pressure differences). - Indoor ventilation depends strongly on outdoor ventilation - Shallow building geometries allow good cross ventilation and buildings with atrium are preferred to patio building in case of compact forms (ventilation through roof under negative pressure)
		Indoor ventilation potential	see outdoor ventilation + building geometry	
Directionality	To determine the orientation of the urban street network according to a compromise between sun and wind orientation		Orientation / sun Orientation / wind	- Solar orientation is more coercive than orientation / wind and might be more decisive. - The optimal oblique wind incidence depends on the geometry of the open space(mean value: 30°) - The street network orientation must take into account the major climatic design recommendations (solar access or ventilation)
Built Envelope	To evaluate the "climatic" performance of the building (energy efficiency, comfort issues, etc.) To evaluate the incidence of architectural choice on urban fabric		Geometry of the building: H, W, L Surface to volume ratio: S/V	- The larger S/V the smaller the compacity of the building and the larger the exposure of the building to the external environment (passive areas vs. active areas) - A building geometry determines the urban fabric typology and hence influences the openness to the sky, urban porosity and directionality.
Landscape	To ameliorate the urban microclimate through shading, evapo-transpiration and wind break		Location of the green: trees, bushes, etc. Specie of the tree, density, form, Size, etc.	- These strategies are complementary to the geometrical choices - The vegetation must keep solar access and ventilation when necessary.
H: Height, W: Width, L: Length				

2 METHODS

An extensive literature review on the effects of urban geometry on the microclimate was carried out as theoretical background (Ali-Toudert 2005). The methodology was mainly based on numerical modelling at a microscale level (Ali-Toudert and Mayer 2006, Ali-Toudert and Mayer 2007a). The simulations results were supplemented by two short-term on-site measurements under typical hot summers: i) the subtropical location of Ghardaia, Algeria (Ali-Toudert et al 2005) and ii) in the mid-latitude location of Freiburg, Germany (Ali-Toudert and Mayer 2007b). A human-biometeorological method for the assessment of the thermal comfort was used, and expressed by the energy-based index Physiologically Equivalent Temperature PET (Figure 1).

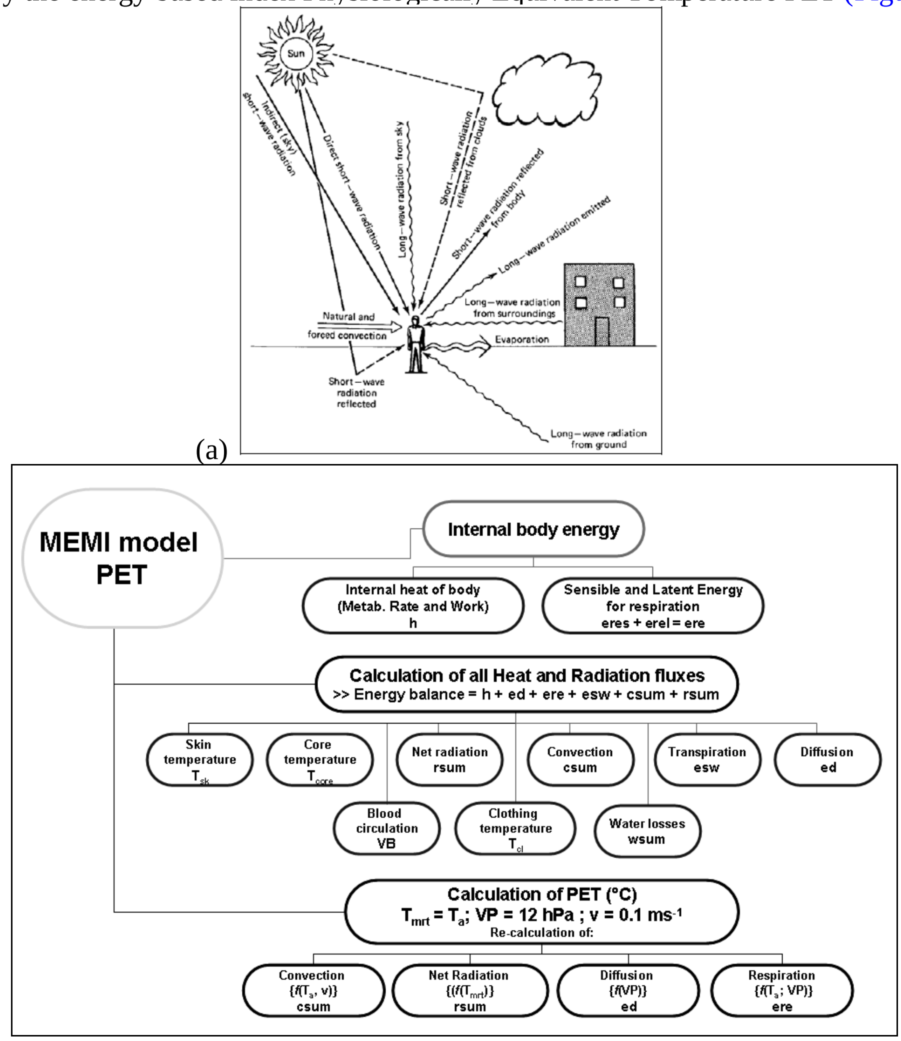

Figure 1: (a) The components of the human heat balance (Houghton 1985) and (b) a scheme of the calculation terms of the Physiologically Equivalent Temperature PET.

3 RESULTS

1.1 Outdoor thermal comfort

In short, the main findings are as follows (see references cited above for details):

1. Air temperature T_a was found to decrease moderately with the increase of H/W. The warming rate of the canyon air follows the irradiances patterns of the canyon facets. As a relatively inert quantity in relation to urban geometry variations, T_a can only be considered as secondary indicator for thermal comfort outdoors.

2. The simulations showed that the thermal comfort is difficult to reach passively in a subtropical hot-dry climate. The duration and period of day of extreme heat stress, as well as the spatial distribution of PET across the canyon depend strongly on aspect ratio and street orientation. Wide streets (H/W ≤ 1) are highly uncomfortable for both orientations. Yet, N-S streets have some advantage over E-W streets as the thermal conditions at their edges along the walls are thermally less stressful. Increasing the aspect ratio improves the thermal comfort for both E-W and N-S orientations, but the N-S orientation still offers better thermal situation. For shallow canyons, implementing shading strategies at street level (galleries, trees, etc.) is the only way to improve substantially the thermal comfort.
3. The differentiated thermal situation observed across the street (centre and edges) is also worthy of note since this will directly influence the design choices in relation to street use, e.g. streets exclusively planned for pedestrians or including motor traffic, and also influence the time of frequentation of urban spaces.
4. These results also confirmed the dominant role of the sun exposure, i.e. the radiation fluxes expressed by the mean radiant temperature T_{mrt} under summer conditions. The heat gained by a standing person outdoors depends strongly on the exposure to direct solar radiation of:
   - the body itself, given by the projection factor f_p and solar intensity G.
   - the surrounding surfaces, which provide additional radiant heat to the body.
5. The maximal amount of heat gain estimated for a pedestrian is recorded for irradiated locations, especially in the early morning and late afternoon, because of the high value of the projection factor f_p as the sun position is relatively low, leading to a large amount of direct solar radiation absorbed by a standing person. This thermal stress is amplified when the air temperature reaches its maximum, typically in the afternoon. Moreover, the standing person absorbs more energy as long-wave irradiance than shortwave irradiance: as a first approximation from measurements about 70 % against 30% in an E-W street with H/W = 1. A strong correlation was found between the total long-wave irradiance absorbed by a standing person and the long-wave irradiation emitted by nearby sunlit surfaces and confirms that the ground surface is particularly important as suggested by Watson and Johnson (1988).
6. Hence, shading is the main strategy for keeping the street area in comfort range because of shading the person itself as well as because it keeps the surrounding surfaces cooler. This was confirmed by simulations as well as by experiments.
7. Using galleries revealed to be beneficial for mitigating thermal stress. This is due to the reduced direct solar radiation received by a human body and to less long-wave irradiation emitted by the surrounding surfaces, in particular the ground. However, discomfort can shortly extend under galleries when the sun is low and reaches the pedestrian and the ground surface. This is more marked for wide canyons and depends on street orientation and gallery's dimensions, i.e. height and width.
8. The asymmetry, as expected, increased the sun exposure of the street in comparison to a symmetrical canyon and hence the thermal stress. Yet, the asymmetrical profile investigated (H_1/W = 2, H_2/W = 1) showed a better thermal situation than a symmetrical street with H/W = 1 in the morning and late afternoon and a trend to cool faster than a canyon with H/W = 2.
9. Overhanging façades as horizontal shading devices (can also be balconies) help to increase substantially the area and duration of shade at street level and reduce further the heat stress. This design solution is advisable for ensuring more shading at street level in the summer and more internal solar access in the winter. Moreover, these "self-shading" façades are expected to reduce the overheating of indoor spaces.
10. The use of a row of trees improves the thermal comfort situation within the canyon, mostly because the direct solar radiation under the tree crowns is strongly decreased. The air temperature Ta in presence of trees is also decreased (by about 1.5 K), That is more than by increasing the aspect ratio. So, here again, shading is the main property of the

vegetation that leads to heat stress mitigation. However, almost no extent of these advantages could be observed in the surrounding space.

1.2 Street design guidelines : a few examples

Shading is the key strategy for promoting comfort in hot-dry climate because it leads to a reduction of i) the direct solar radiation absorbed by a pedestrian, ii) the heat released by the surroundings, in particular the ground, and iii) the air temperature as a secondary effect.
Manifold design possibilities based on promoting shade can be suggested for controlling the microclimate, and hence, the human comfort outdoors: i) a judicious combination of aspect ratios and orientation, ii) by arranging galleries, planting trees, greening the façades or by using other shading devices on the walls and over ground surfaces.
The examples below seek to illustrate realistic situations and support the following discussion. Although, the reference study was mostly completed for a subtropical location with extreme hot-dry climate for summer conditions, it is believed that the design recommendations discussed here can be as efficient as for transitional seasons and also applicable to less extreme climates such as mid-latitudes with typical hot summers (e.g. Freiburg). The Mediterranean basin, for instance, experiences to a large extent similar irradiation potentials in the hot season (see Arnfield 1990). Obviously, adjustments related to sun course geometry (zenith and azimuth angles) accounting for latitude differences have to be considered (Arnfield 1990).
Designing an urban street is primarily conditioned by:

1. Street utility: including the structural role of the street in the whole urban plan, implying scale (i.e. absolute dimensions: width and height), activity, and use (pedestrian streets or including motor traffic). This has a direct impact on the period of time at which comfort is essential (frequentation time by people) and also the area of the street where comfort is at most required (whole area, street edges versus centre, etc.).
2. Building use: domestic (housing) or non-domestic (offices, schools, etc.). Domestic buildings are concerned with comfort the day round and require passive solar gains. South, south-east or east exposures of the façades are the most suitable. In non-domestic buildings, comfort is mostly crucial during the daytime where day-lighting is the main concern. The potential of natural light is almost equal for all solar orientations and is much more sensitive to the sky view, i.e. aspect ratio.

Usually, the street orientation is chosen first and the aspect ratio is set according to the orientation. The street orientation, if not already determined by non-climatic arguments (site constraints, surrounding built environment, regulations, etc.) should take into account the needs for solar energy inside the buildings and as much as possible pay attention to the dominant wind directions for promoting ventilation or protecting from cold winds. An E-W orientation is well known to be preferable if solar gains have to be maximized. Intermediate orientations are less optimal but still provide a good potential of sunlight and daylight. N-S orientation is appropriate for daylight issues but requires a good protection of the façades from the sun in the summer.
As a first rule of thumb, the urban canyon can be divided into two parts: i) street level and ii) building part (Figure 2), which refer to outdoor and indoor issues, respectively. The street area is in turn subdivided into 3 sub-spaces: the central part, the edges and possible extensions in the building basement in form of galleries.
Given that the passive solar gains are needed only in the upper building part, then, the “effective” aspect ratios for the façades (expressed by α_1 and α_2) are less restrictive than the absolute aspect ratios, applicable for the street area (β_1 and β_2). Secondly, it is advisable to offer a diversity of arrangements at street level in order to increase the probability for a sustained frequentation of an outdoor space. Published results put forward the necessity of differentiating between wide and deep streets ($H/W \leq 1$ versus $H/W > 1$) as a first approximation.

Wide streets allow a good solar access in the winter but are highly uncomfortable in the summer at street level. Detail arrangements are thus required. Deep streets are better protected in the summer but do not support winter issues.
Figure 3a shows a typical wide street flanked by 2 rows of trees on both sides, either oriented N-S. Large and high trees act for shading on the lateral sides while the central part is foreseen for motor traffic and kept untreated. In case of E-W orientation, adding galleries is advisable. Deciduous species with sufficient distance from the south wall avoid the obstruction of desirable solar gains in the winter.
Figure 3b shows another example of a wide street canyon of H/W = 0.6. The street is E-W oriented and allows optimal internal solar gains on the south façade. In this case, the largest part of the street would be highly uncomfortable if no shading strategies are planned.

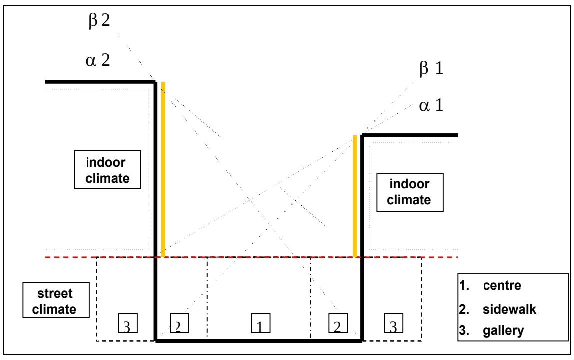

Figure 2: Scheme on the subdivision of a street canyon volume according to climatic design needs

The street area is divided in sub-spaces consisting of pedestrian areas and motor traffic areas. Pedestrian areas are placed on the southern half part of the street, arranged under galleries or protected by vegetation. Trees are planned so that they maximize shade through their large crowns and high size. At the same time they are at some distance from the south facade to prevent overshadowing in the winter. Trees are preferably deciduous in order to save solar access indoors in winter and for people sitting outdoors in the winter.
Motor traffic is also located on the north side on the potentially less comfortable location. On the south side a deciduous tree can be added to prevent from overheat in the early morning and late afternoon in the summer season if required by the activity taking place at that part of the canyon. The relatively large aspect ratio promotes a rapid nocturnal cooling.
Figure 3c shows an example of higher aspect ratio with an asymmetrical geometry especially advisable when high plan density is required. The walls have to face the sun, i.e. street axis preferably oriented E-W, NE-SW or NW-SE. The flanking buildings have different heights. The wall facing the sun predominates with a large openness to sky of the building part promoted by the lower height of the opposite building.

At street level, horizontal overhangs, e.g. in form of galleries and trees are planned to keep the whole space comfortable since exclusively foreseen for pedestrian use. Moreover, a special attention has to be given to the surfaces themselves. Ground pavements should be preferably of light colour, porous and/or of thin layer materials to keep lower surface temperatures. Pavements mixed to green surfaces for promoting evaporation from underground are also advisable (Asaeda et al 1996, Ca et al. 1998), especially in latitudes where summers are not dry. Building materials also play a role: High thermal capacity and high albedos help to reduce the surface temperatures further and thus the heat released (Rosenfeld et al. 1995).

An urban structure composed of small size buildings and possibly staggered in a checker-board pattern, may be preferred, as this promotes a much uniform wind flow and eliminate stagnant air zones. Since ventilation is strongly reduced even for wide canyons in case of perpendicular flow, it is suggested that buildings of medium height with moderate aspect ratios provide better ventilation than low-rise buildings with small aspect ratios, due to stronger convergent flow from the sides and higher wind speeds. An oblique incidence of wind (see Freiburger's canyon) offers good ventilation potential at street level.

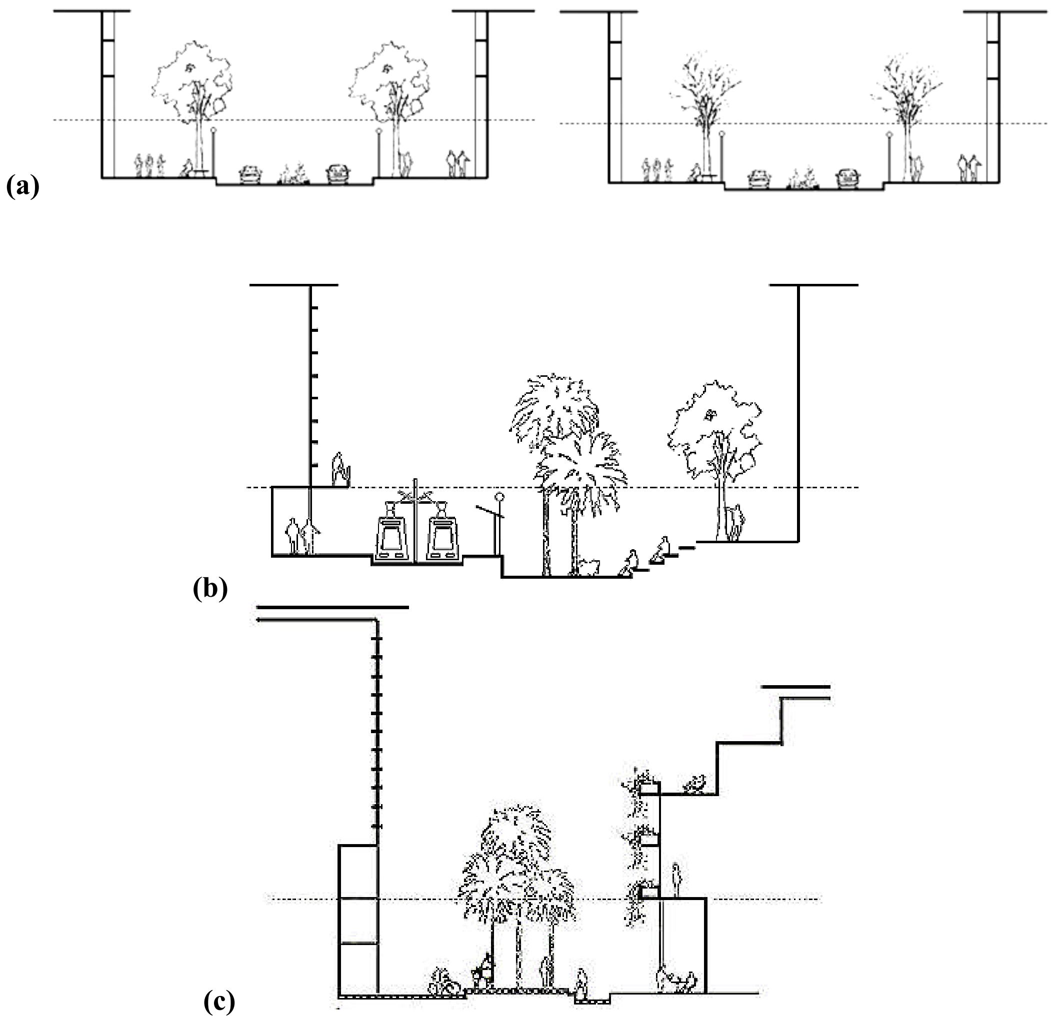

Figure 3: Some examples of urban streets (a) a wide canyon combining motor traffic and pedestrian areas protected by deciduous trees. (b) a wide street canyon oriented E-W, combining comfortable pedestrian zones and motor traffic. (c) an asymmetrical canyon combining summer comfort at street level, winter solar access and high density.

4 CONCLUSION

A number of interesting questions arise in the course of this study:

1. More field measurements are required for validating numerical results, from which the effects of the urban parameters investigated in this study, i.e. aspect ratio, orientation, vegetation, galleries and self-shading façades. This is particularly sensible for a better estimation of the energy gained by a human body (and consequently T_{mrt}), which can improve modelling parameterisations.
2. To extend the study to night-time situation by investigating the effects of urban geometry on the nocturnal cooling (of the street and buildings).
3. Human comfort is a multifaceted issue which combines physical, physiological and psychological dimensions. Yet, important methodological differences in assessing comfort were

observed. It is still difficult to interpret the actual human thermal sensation from the currently used thermal indices. Complementing energy-based methods with adaptive methods (social survey's) is necessary as a next research stage for a better understanding of human comfort and eventually setting a universally applicable tool for comfort evaluation.

4. More connection between architectural and urban scale is highly advisable, since urban buildings are in the practice primarily conceived to cope with indoor comfort. Developing microscale numerical tools which assess simultaneously the effects of urban geometry on outdoor and indoor climate (i.e. energy efficiency of buildings) is a promising alternative.
5. The outdoor thermal comfort is one but important issue in a sustainable urban design. Further aspects including health and well-being issues, energy and resource savings, reduction of environmental loadings, etc. are required to build a comprehensive sustainable urban design method. This latter topic is handled in another contribution to this conference.

5 REFERENCES

Ali-Toudert, F. 2000: Integration of the climate dimension in urbanism. Master Thesis. School of Architecture Algiers EPAU.

Ali-Toudert F, Bensalem R, 2001: A methodology for a climatic urban design. Proc. of the 19th Conference on Passive and Low Energy Architetcure (PLEA), Florianópolis, Brazil, 7-9 November 2001: 469-473.

Ali-Toudert, F. 2005: Dependence of outdoor thermal comfort on street design in hot and dry climate. Report of the Meteorological Institute University of Freiburg i. Br., PhD Thesis. Report 15. http://www.freidok.uni-freiburg.de/volltexte/2078.

Ali-Toudert F, Mayer H, 2006: Numerical study on the effects of aspect ratio H/W and orientation of an urban street canyon on outdoor thermal comfort. Building and Environment, 41: 94-108.

Ali-Toudert F., Mayer H., 2007a: Effects of asymmetry, galleries, overhanging façades and vegetation on thermal comfort in urban street canyons. Solar Energy, 81, 742-754.

Ali-Toudert F., Djenane M., Bensalem R., Mayer H. 2005: Outdoor thermal comfort in the old desert city of Beni-Isguen, Algeria. Climate Research 28: 243-256.

Ali-Toudert F., Mayer H., 2007b: Thermal comfort in an east-west oriented street canyon in Freiburg (Germany) under hot summer conditions. Theor. Appl. Climatol. 87, 223-237.

Houghton D.D. 1985: Handbook of applied Meteorology. John Wiley and Sons. New York.

Arnfield J. 1990: Street design and urban canyon solar access. Energy and Buildings 14: 117-131.

Asaeda T., Ca V.T., Wake A. 1996: Heat storage of pavement and its effect on the lower atmosphere. Atmos. Envir. 30: 413-427.

Ca V.T., Aseada T., Ashie Y., 1998: Utilization of porous pavement for the improvement of summer urban climate. Proc. 2nd Japanese-German Meeting "Klimaanalyse für die Stadtplanung". RCUSS. Kobe University, Sp. Rep. No. 1: 169-177.

Moughtin C. 2003: Urban design, street and square. Architectural press. Amsterdam.

Rosenfeld A.H., Akbari H., Bretz S., Fishman B.L., Kurn D.M. Sailor D, Taha H. 1995: Mitigation of urban heat islands: Materials, utility programs, updates. Energy and Buildings 22, 255-265.

Watson I.D., Johnsson G.T. 1988: Estimating person view-factors from fish eye lens photographs. Int. J. Biometeorol. 32: 123-128.

reCHARGEDcity[21+] - from a perforated, shrinking city to a energy-self-sufficient town

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ABSTRACT: The diploma thesis reCHARGEDcity[21+] sketches a vision for an energy self-sufficient, climate adapted urbanism in a post-fossil age. Potentials for sustainability, image and quality of life of the urban space of a shrinking city will be shown.
A scenario was developed for a gradual conversion of the city's technical infrastructure into decentralised regenerative systems, illustrated by the example of treating waste water locally through a reed bed treatment system and decentralising electricity and heat production with fuel cells (combined heat and power units (CHPs)). An almost complete water cycle as well as a completely self-sufficient energy supply within the former city-area will be achieved. The usage of decentralised, regenerative supply and disposal tools offers a range of synergetic advantages: revitalisation of fallow areas and refurbishment of free spaces opened up by demolition with attractive and financially viable elements that are able to replace the successive breakdown of the city's central technical infrastructure.

1 INTRODUCTION – THE PROBLEM OF SHRINKING CITIES AND THE OPPORTUNITY FOR SUSTAINABLE DEVELOPMENT

The phenomenon of shrinking cities is not new. It is not limited to regions—indeed it affects all industrial countries. Demographic, societal and economic changes alter cities and quarters. Existing urban structures must adapt to those new challenges. Especially pronounced is the phenomenon of the new German federal countries caused by the upheaval following German reunification.

Two problems caused by the process of urban shrinking are essential for the understanding of our work: Whenever the population of a quarter drops significantly to a certain level, the conventional central technical infrastructure breaks down. An example in the field of water supply and disposal are drain lines becoming over dimensioned with those changed conditions. Either fresh- or wastewater remains in the pipes for too long, so hygienic standards are endangered. For a few years already some East German cities have had to flush their pipe system with freshwater as a short term solution—an effort that is financially and ecologically prohibitive. In the long run conversion of the existing pipe work is inevitable. The problem is, that financial requirements are confronted with a decreasing population which reduces the city's tax base. The possibility to react sinks dramatically.

The second aspect of the urban shrinking process is the overcapacity of the housing market especially in Eastern Germany as a result of the residential building politics of the former GDR. Because of this, the major focus of the urban restructuring has been deconstruction. Wherever buildings are torn down open wounds remain—new free spaces emerge that, due to lack of funds, become makeshift grassy areas without aesthetic or functional qualities, but nevertheless are a burden to maintain.

Figure 1. Typical atmosphere in a shrinking city with its fallow areas

A further base of the thesis is the global debate about sustainability and climate change. The authors are convinced that a move towards sustainable structures is especially inevitable in the field of architecture and urbanism and must be intensified promptly. It is this actuality that we see opportunities for shrinking towns and cities that we would like to further illustrate.

2 ELUCIDATION OF THE DIPLOMA reCHARGEDcity[21+]

2.1 *Development of scenarios and explanation of the main urbanistic elements*

The gradual conversion of the city's technical infrastructure into decentralised regenerative systems is exemplified by Köthen in Saxony-Anhalt, a medium-sized town of 30.000 inhabitants, situated 25 km southwest of Dessau. The process of city conversion, shown in this paper is subdivided into three phases, with a target comletion date of 2050 – a time without fossil energy. Starting with the current status quo the major fundamentals of the project's further development will be realised by 2015. In the scenario shown, a one hundred percent supply of electricity and heat for within today's city limits will be achieved by 2030. By 2050, it can be increased to a 125 % supply, which means that Köthen will then become a surplus-energy-city by that time.

In order to start drafting a scenario encompassing now until 2050, a differentiated examination of relevant -tendencies of delevopment is necessary. The authors therefore created a comprehensive storyboard taking into account developments in the fields of society, demography, sociology, climate, energy, technology, mobility, agriculture and medicine. In this paper only the most important factors for the design will be mentioned.

Forecasts of regional climate changes predict, that the average summer in the year 2050 in central germany will be much hotter and drier than today, comparable to an average summer of present-days in Southern Europe. That means, that a huge problem of sufficient water supply during summertimes will develop. On the other hand it is expected that the average winter will become milder than today, comparable with the winter of 2006/2007. Additionally there will be more frequent occurances of intense rain and, in consequence, the area will have to deal with floods.

The authors act on the assumption, that we will have reached the postfossil age to a large extent by the year 2030. Because of the increasing shortage of fossil resources, especially petroleum, these will be nearly exclusively provided for chemical industries and no longer used as cheap fuels like today. Decentralised and regenerative energy-production- and distribution-systems will dominate the future's energymix, not least, because the costs for energy will rise excessively. Similarily, changes in the transport sector are another fundamental determinant. Increasing efficiency, and the reduction of private transport are the main factors in that sector. In the fields of demography and sociology the current gap between the rich and the poor is expected to widen. New target groups,which are in the process of forming,, for example "young elderly people", will become the dominant societal group. A massive reduction of public welfare funds and a corresponding growth of self-organized networks will be mentioned as the last determinant in that sector. Essentially for the design of urban development, will be a concentration of the population in cities over 20,000 inhabitants, and as a consequence a disappearance of villages in rural areas.

Another base for the scenario designs for the city of Köthen until 2050 is formed by the simulation of the development of the city's population. This simulation is based on a hypothetical extrapolation of today's prognosis, combined with relevant factors from the afore-mentioned storyboard and influences from a differentiated examination of the city's districts and its endogenous development potentials.

It is assumed, that there will be a halving of the city's population figure by 2050 – from 30,000 inhabitants in 2006 to 17,000 inhabitants in 2050. That might seem shocking, but in fact it is a boom-scenario, expecting a strengthening of the existing and a development of new potentials. In chapter 3, the authors will report about the contributions, which a sustainable urban development process might provide to this scenario.

The setting of the shrinking process is also based on a detailed analysis of the city's district-potential. In respect of factors like proprietary structures, life-cycle-statuses, the sustainability of building typologies, target group analysis and age distributions retrogression of the cropped areas into three core-zones has been suggested. Therefore, today's city limits remain clearly accentuated from the surrounding areas.

The first core-zone consists of the oldtown quarter with the adjacent Wilhelminian style districts, with a broad range of societal and demographic target groups. The second core-zone is formed by a garden city-district with detached and semi-detached houses, which focuses on future self-sufficient inhabitants. Finally, the third core-zone is constituted by the youngest and smallest part of the existing precast concrete slab building district, which will accomodate the need for low price housing in the future, just as it does today.

Figure 2. Over-all plan of the converted city of Köthen in 2050

The new free spaces, resulting from demolition within the city's current limits, entitled "exurban" areas by the authors, will be converted into new types of urban agricultural spaces and will be uniformly designed with agroforestry. Agroforestry means in this case, that a cultivation of biomass in the form of fast growing, perennial herbage (Sudan grass (sorghum sudanense), Szervasi, Miscanthus and ryegrass (lolium)) is combined with rows of trees, which are situated in the herbage. With this combined cultivation method, a yield increase of up to 30% can be achieved. Additionally, the trees provide shelter against the increasing climate extremes, for example as a shade-dispenser or as a wind shield.

A differentiation of the planting density, the cultivation of different kinds of herbage and trees and a change in the orientation of rows of trees will instigate a new kind of urban freespace, with a diversified appearance, high functual and asthetic qualities with a good level of biodiversity. These exurban areas serve as a spacial element, which interconnects the core-zones and helps to let the city's outline remain clearly accentuated from the surrounding.

Beside the exurban areas another typ of new urban freespace forms the cities future appearance. As initial-areas for the regenerative urban development process, today's numerous fallow areas, situated mostly inside the housing-blocks of the Wilhelminian style-core-zone, will be opened promptly to the city and will become revitalized with new functions and a new appearance. A reliefied mosaic arises, which is scaled in height and adapted to the natural devolution of the topography. The four major elements of this freespace-mosaic are: Firstly the reed bed treatment systems, serving as a decentralised waste water treatment, close to the buildings, which are integrated in a cyclic system of reuse of the treated greywater.

Secondly to mention, there are the areas for retention. Their duty is to work as a buffer for intense rain occurences. The rainwater can be collected in these spaces and drain naturally. Through this, a major contribution to the support of the ground-water table can be made during the winter periods, attenuating the periods of drought throughout the summertime. Thus, the groundwater-regeneration-rate can be raised strongly. The retention-spaces are as well situated inside the housing-blocks and they are integrated in an over-all-system of open trenches, These trenches serve primarily as a drainage system for surplus-water from the water-usage-cycle, but they can be used as well for the drainage of remaining rainwaters. The offtake of the waters is adjacing the natural incline and forms a zoning-criterion for the exurban freespaces: In areas, watered with the inflow of the trenchsystem from the remaining settlement districts, the agro-forestry-tree-rows are planted in double-rows. A plantation of alimental crops takes place in the interspace between the trees.

Figure 3. Atmosphere of every day life in Köthen in 2050

Further components of the freespace-mosaic inside the housing-blocks are fruitgroves, with specific fruits for each housing-block and the afore explained energy-herbages, serving as elements of design and identification.

The major existing areas of recreation and parks in the innercity are not endangered by this approach of establishing new urban freespaces in the exurban and core-zone areas. Quite the contrary, these existing parks are embedded in a network of new functional freespaces.

Talking about the spatial organization of the city, the areas inside the housing-blocks in the Wilhelminian-style-core-zone are combined in groups of four to six housing-blocks, which are arranged around newly developed quarter-centres – so called hubs. These hubs serve as the social "heart" – multifunctional venues, where urban functions are concentrated punctual, which generates a stimulation of public spaces in these areas.

The third component of spatial changes in the cityscape, beside the revitalised fallow areas and the hubs, are formed by newly developed multifunctional zones in the streets. Under estimation of a reduced traffic-emergence with optimized vehicles, thinking about new concepts of using and stimulation of the streets, which are in average 15 meters in width is mandatory. The new multifunctional zone, consists of the mentioned open watertrenches, which expand punctually into basins. Adjacent to these basins, tiny places are designed, each related to a group of houses. The surface of the water support a positive shaping of the microclimate during the summer, as they serve as evaporation-spaces. The future forms of parking-spaces are integrated in the multifunctional zone as well. They are called "docking-stations", because parked hybrid-vehicles will be charged with electricity and gas. Subterraneous dustbins will eliminate today's appearance of dustbins in the cityscape. Partly, they are interlinked directly with the over-all-system of the urban cycles of matter. Trees are used as a throughpassing element of design and as shade-dispenser.

2.2 *Elucidation of the over-all energy-concept*

In this scenario, a major base of the urban energy-supply is formed by the cultivated biomass, planted within the today's city-limits in the exurban areas.

Due to the cultivation-method of agroforestry, explained in chapter 2.1 yields of 25 tonnes of biomass per hectar and year can be achieved. The biomass will be harvested once a year, and will be transformed and purified into timbergas, as a secondary energy source. Additional to the specially cultivated energyplants, the already accumulating biomass, like loppings, the city's organic waste, and so on will be used for production of timbergas as well. This is a special synergetic effect. Aroused by the usage of the garbage, the cycle of matter can be closed locally and the ressources remain on-site. The timbergas, produced this way can be supplied to the gas distribution system without any difficulty, it can be allocated in any order and it can be stored, nearly without any losses. The ability to be stored nearly without any losses is a great advantage of gas in contrast to the difficulties of storing heat.

Another major component of the energy-concept is formed by the city's differentiation into two parts with different enegergetic needs and different urban development-potentials. On the one hand, there are the core-zones, which will still be in existence in 2050, and on the other hand, there are the so called "observation areas" in the exurban spaces. The development of these areas is difficult to estimate and not planable in depth. Therefore, the buildings in the observation areas will each get single heating systems, powered by timbergas, which will be delivered by the existing gas distribution system. A single building control system, as well for heating as for the hot water supply provides high flexibility and good adjustment options to changing conditions, so a flexible process of shrinkage is possible in these areas. Nevertheless, a sustainable and carbon dioxide neutral energy-supply is given, resulting from the supply with timbergas.

In the core-zone of present-day's city center a gradual development of a local solar generated heat network is initiated. This system consists of the addition of many individual local heat networks, each of them with the dimension of a housing block and in principle beeing able to work self-sufficient. The buildings in this local heat network are supplied with energy and heat, produced locally in timbergas powered fuel cell CHP`s. In addition, solar generated heat, produced by building-integrated plane solar thermal panels is supplied into the grid. The annual solar coverage reaches 65%, both for heating and hot water preparation. Through this a respectabel amount of timbergas and therefore finally a lot of biomass can be saved. The surplus amount of heat, produced during the summer months is stored in permanent storage tanks for an use during the winter. This is mandatory to get into the position to reach the afore-mentioned high solar coverage. The permanent storage tanks consists of phase changing materials (PCM), so they are able to work very efficient with just a marginal loss of energy.

To cover the electricity demand, a gradual development of a building-integrated solar power plant fleet is essential, using photovoltaik (PV) panels. The extensive facades of the precast concrete slabs are very suitable for this demand. Covering them with PV-panels, they become energy-collectors, producing more energy, than they need themselves, supplying the produced electricity into the excisting grid, so they can cover the demand of the surrounding buildings as well.

Over-all, a close meshed supply-grid with a multitude of producers and consumers is installed. The minimization of circuit and storage losses is a benefit of the decentralized structures. The efficiency of the complete system will be raised by using building-specific potentials. The presented future energy-supply-concept consists of a decentralized regenerative network and a crosslinking of the consumers and producers, aiming on an efficient supply and use of energy. The intensification of synergetic effects in interrelation between the participants of the installed network will be used to boost efficiency both in producing and supplying processes. The material flows of the supply and disposal systems are accounted with a holistic viewpoint and are integrated in an over-all concept.

Energetic assumptions

Biomass production	annual yield benefit of 25 t/ha, heat value: 4,5 kWh/kg
solar thermal panels:	solarisation: 350kWh/m^2 a
photovoltaics:	solarisation: 350kWh/m^2 a
storage	storage of the solar generated heat in special permanent PCM - storage tanks. loss of circuit and storage: 15%/a
fuel cell CHP	hours of operation: the high average output of 4000h/a can be reached, because the surplus amount of heat is stored in the permanent PCM storage tanks

3 SUMMARY – CHANCES AND ADVANTAGES

The authors wish to link the diploma now in the following with the situation in 2007, and on in addition they want to take the chance to resume all the synergetic advantages of the presented urban development strategy.

First of all, it should be refered to the tendencies of the current global warming debate. In May 2007, the UN-climate report reminds that vigorous changes in association with carbon dioxide emitating processes are mandatory by 2015, if human mankind wants to avoid a massive climate change. At the end of 2006, the stern-report argues, that the implementation of prompt action to reduce the output of carbon dioxide is economically much cheaper than later reactions. By the time, the consequential and adjustment costs will rise strongly. In March 2007, the European Union agrees on an over-all carbon dioxide reduction of 30 % until 2020, in comparison with 1990. Germany commits itself even on 40 % reduction during the same period of time. European-wide and national agendas of implementation will follow.

Listing these facts, it should not be constructed a scenario of harassment. Quite the contrary, the presented diploma tries to show exemplary ways to deal in an innovative way with the challenges. The current situation offers chances and options – for example for local authorities, whom decide precociously to follow a consequent development and conversion strategy.

The paper reCHARGEDcity^{21+} recommends a two-way strategy in relation to climate change. On the one hand, a prompt conversion can contain the effects of and a further increasing of the changes. In addition, it is advisable, to incorporate the predicted changes into the urban planning process at an early stage, so that it is possible, to react calmly and tactical. In both cases, an early action means an advance in time.

The afore-highlighted combination of the topics city shrinkage and sustainable urban development, with a focus on the conversion of urban supply and disposal tools into decentralized systems overs a range of synergetic advantages. They should be explained here in an overview. Planned at an early stage, together with relevant actors, like urban planning departments, supply companys and housing societys, inevitable investments in new systems can be made at most, while already life-cycle dependend modernizations of the infrastructure are pending. The chance of displacing expensive and complex conversions of the old, centralized supply and dispossal structures with the installation of decentralized, regenerative systems appears in cities, affected by shrinkage. Mandatory investments, as a reaction to the dicline of population figures, can be channeled to climate neutral progressive technologies. Resulting from their decentralized network structure, they are better capable to react flexible to fluctuations of the local demand and so, they are better qualified for dynamic altering cities. In ideal cases, a fortunate combination of users and producers in such a network can arrange a minimization of peaks and depressions.

Decentralized technologies, like the presented reed bed treatment systems and the cultivation of biomass, got a high space requirement. That means a big chance for the design and reutilization of new arising or already existing and orphaned urban free spaces in shrinking cities. In contrast to unused spaces with ongoing maintenance costs, the new urban free spaces are economically self-sufficient, resulting from their technical function, which means that they deliver simultaneously an important infrastructural contribution to the persistance of the city. There exists a big synergetic surplus value in the chance to form new livable and appealing "green" cityscapes, if the new land utilisations are implemented with a holistic viewpoint, for example by carefully chosing water- and biomassplants under a creative viewpoint and integrating them aestheticly and harmonicly into the cityscape.

In addition, there are chances for housing societys and supply companys to built up new alternative sources of income if they invest in decentralized regenerative technologies, for example in the role of an energyproducer or a wastewaterdiposer. These sources can become important in times of changes. Above all, there is a chance for housing societys, to offer their customers a rollback of the auxiliary costs, if they join such projects as operators ot the infrastructural systems. A reduction of the auxiliary costs is often the only chance to tie tenants with price advantages in areas, where the squaremeter-prices at the residential market are run down.

A precocious and consequent adjustment of urban planning strategies towards a sustainable development, which is shown in the cityscape and communicated offensively can create a new urban identity, as well as it can strengthen already existing identitys in a fruitful manner. Thinking about the communication with it's inhabitants, a clear and consequent pursuit of such a progressive development perspective can create a positive disposition in an effective way, so that the often observed lethargy and the loss of perspective can be broke through. Competing with other cities a resolute action might become a unique selling point and a temporal advantage.

Research and development in the field of decentralized infrastructural systems might strengthen existing infrastructures, like in the case of Köthen the branch of the FH Anhalt (university of applied sciences) and an existing technology centre, as well as it can forward the settlement of new institutes and companys. KnowHow might be tied on-site, the settlement of producers of regenerative technologies might be forwarded.

Finally, a new typ of city arises, a "green" city with new kinds of functional and attractive freespaces and a quite high over-all quality of life. Keyfunctions of a medium-sized town can be combined with progressive forms of green space residentials, right in the centre of the city, without breaking apart the city's structure.

4 OUTLOOK – FURTHER ADVANCEMENT

The authors are working on a progressive conversion of the diploma thesis on different levels. Research on the setup of decentralised, regenerative power grids is expected to be conducted by January 2008. Projects for base work and prototypes are in the preparatory stage: for example, all-encompassing feasibility studies and CO^2 balancing form the base of further steps for the conversion to an energy self-sufficient city. Negotiations are in process regarding prototypes of energy reconstitution of city quarters in combination with the set-up of urban biomass production and utilisation cycles.

5 BRIEF INTRODUCTION OF THE AUTHORS AND CONTACT

The focus of the authors studies is lying in the field of sustainable development in architecture and urban planning, which results since 2004 in a deepened research of the combination of the topics city shrinkage and sustainable development in theory and practice.

Felix Lüter: Proffesional practice since two years in the field of integrated holistic urban development. Involvement in the formulation of integrated urban development concepts, in public programms “Stadtumbau West” and “Soziale Stadt”.Prized contribution in the federal competition “city shrinkage as a chance”, advertised by the Schader Stiftung and the Werkbund Baden Württemberg. Publication of an article about city shrinkage in the magazin “Der Bayrische Bürgermeister”, september 2005.

Thomas Meinberg: Works at the department of energy efficient building design, amongst others in the research project “elife” – life cycle analysis and optimization in the field of residential concstruction, involvement in the publication of an energy atlas and in a DBU-research project “examination of the sustainability of excisting buildings”, as well as implementations of energy accountings. Planed and realized a low-energy-annex and a refurbishment of an old building, converting it into a three-litre-building.

Methods in sustainable urban process

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ABSTRACT: The urban planning process is the base to land use changes and the support to human activities. By acting in the management of the territory, at environmental, economic and social levels, it brings up the possibility to satisfy the population needs and promote conformity between the stakeholders. The planning process is a privileged tool to operationalize the sustainable development principles. Therefore it is needed to create an operative methodology to achieve an efficient Sustainable Planning Process, interfering in both temporal and territorial scales, and finding the right balance between the sustainability factors. It is proposed a theory model that leads to the Sustainable Planning Process, and also its practical appliance to the case study "Casas de Sto. António", located in the Barreiro's municipality, and integrated in Lisbon Metropolitan Area. It is demonstrated how the process can be operationalized, by presenting the verified results of its implementation in the study area.

1. INTRODUCTION – THE SUSTAINABLE DEVELOPMENT THROUGH THE PLANNING PROCESS

The appliance of the Sustainable Development concept, have been increasing in the last decades, and nowadays it is an important preoccupation in the processes involving interventions on the territory, once that it constitutes the support for human activities. The Sustainable Development concept was first introduced in two United Nations conferences about environment and development (WCED, 1987), where the need of new global and local development strategies was recognized.

Through the Sustainable Development concept it is intended to "meet the needs of the present, without compromising the ability of the future generations to meet their own needs", by guarantying the environmental quality, economic development, and social equity, in an inter-generation perspective. Through the Sustainability concept, the planning interventions, must balance the environmental, economic, social and cultural factors. This concept can only be fully operationalized through an integrated approach of these factors.

The planning process is the base to land use changes and the support to human activities. By acting in the management of the territory, at environmental, economic and social levels, it brings up the possibility to satisfy the population needs and to promote conformity between the main stakeholders. Has it's been mentioned in the Green Book for The Urban Environment (UE, 1990), the city should start to be seen has the driving force toward the actions leading to the Sustainable Development.

The complete implementation of the Sustainable Development principles, will only be possible through territorial planning "…the regional and urban planning is directed to the communities, its population and for the use of the land and economics' structures, through processes of goals definition, planning actions and rules…" (Slocombe. 1993). Therefore the urban planning process has a fundamental role in the carrying out of the Sustainability principles and goals.

The Sustainable Urban Process should guide the intervention actions to efficiency, acting in both temporal (short, medium and long term) and territorial (local, regional, global levels) scales, in new construction areas, or in existing urban areas.

In order to implement the sustainable principles in an efficient way, it becomes necessary to develop a new operative methodology, which leads to the Sustainable Urban Planning Process.

2. THE SUSTAINABLE URBAN PLANNING PROCESS

The promotion and real implementation of the Sustainable Development concept is possible through the urban planning process, which has to guarantee the equitable integration between the Sustainability factors (environmental, economical and social). The link, that is necessary to achieve, between the Sustainable Development principles, and the planning process, gives the key to the urban development success.

The nowadays planning process has already showed its disarticulation with the charge capacity of the territory, and also with the contentment of the population needs (sometimes placed by the intentions of the enterprises promoters). As well, the current process does not correctly fit in the Sustainable Development concept, once that the environmental and social issues not always have the same attention than the economic ones. The maintenance of the present urban planning process will have serious consequences for the future generations, once that it is consuming the natural resources, consequently damaging the natural environment, inevitably influencing the social level interventions.

For these reasons, becomes necessary to create a “new” operative urban planning process, which by its integrated approach, leads to Sustainable Development. This “new” process should be based in strategies that promote improvement in the quality of population’s life, efficiency in the urban infrastructures network, enhancement in the urbanity relations, the same with better efficiency in the interactions with the natural environment. It is required that the process also answers the challenge to land use transformations, social relations and to urban space environments, promoted by Sustainable Development.

In the way to achieve sustainability through planning interventions, it is necessary to consider numerous variables (depending on the site specifications), treat them in a skilful way and be certain that the population, as well as the other stakeholders, follow all this process. Only trough the effective participation of the population is possible to build an efficient and clear urban process.

The process’s structure should provide the necessary flexibility and adaptability, so that it can be easily applicable to different intervention dimensions and realities. It structure must as well be enough inclusive to enclose all the intervention course of action, from the goals definition to the evaluation and validation process.

3. THE SUSTAINABLE URBAN PLANNING PROCESS METHODOLOGY

As it was mentioned before, it is necessary to build an operative methodology, leading to Sustainable Planning, by promoting territorial approaches that do not compromise the future generation’s expectations, and encourage the natural resources sustainable management. The Sustainable Planning Process specifications demand a global view through all the involved issues, and consequently a holistic design of the project. These specifications require a methodology of easy appliance in the different intervention levels, from the Project – establishing the conceptual model to urban quality solutions – to the Construction – defining the technologic processes and the constructive materials, in order to minimize environmental impacts – and the Use – controlling use procedures of spaces and resources.

This “new” method must be specific and easily applicable, supported on the options reversibility and flexibility, being possible to adapt them to each case study characteristics, always regarding the Sustainable Development strategic goals. The Sustainability strategic principles witch directly influence the urban planning process are:

– Sustainable use of natural resources;
– Control of the disordered urbanization;
– Satisfaction of the population needs and expectations;
– Reduction of the waste and consumption;
– Promotion of local economy and employment;
– Preservation of natural, economic, social and cultural diversity;
– Promotion of energetic efficiency, and renewal energies use;
– Encouragement of new mobility modes;
– Involvement of the local population in the urban planning process.

From this method should also result the promotion of land use changes fundamental principles, witch provides:

– Social welfare – by including natural leisure areas;
– Environmental efficiency – by minimizing the environmental impacts;
– Economic efficiency – by improving the durability of urban systems;
– Inclusive urban design – by creating conditions of total accessibility to the new urban areas.

Considering this principles through an operative urban planning process it is possible to guarantee that the implementation result fits in the Sustainable Development concept.

The Sustainable Urban Planning, next presented, is constituted by four sequential stages, included in the normal development of an urbanistic intervention.

1. Intervention aims definition – strategic goals
2. Reference situation analysis – environmental, economic, social and urban analysis, restraints and potentialities recognition, criteria definition
3. Plan design - survey and rearrange of urban/rural property limits, selection of the restraining elements, strategies and sustainability factors, public spaces and facilities location, road design, buildings setting, conclusion of the project's proposal
4. Implementation – design of implementation technical sheets, and evaluation processes.

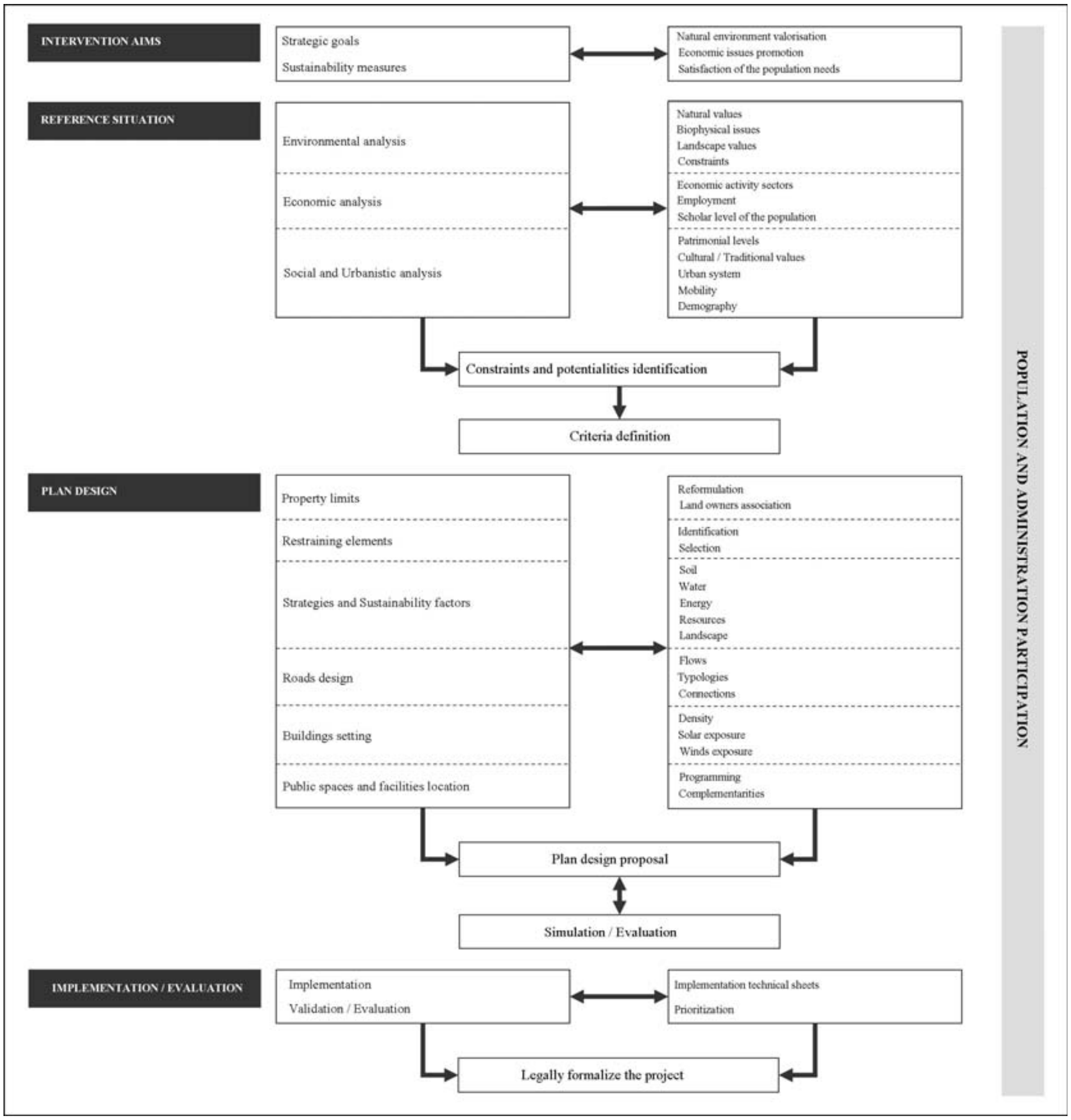

Figure 1. Sustainable Urban Planning Process methodology

The process (during all its stages) must have the population and other intervenient entities participation, should be validated and constantly evaluated, so that the involvement of the interested stakeholders and its identification with the final urban proposal can be really guaranteed.

4. APPLICATION TO THE CASE STUDY “CASAS DE STO. ANTÓNIO”

It is intended to show the operational working of the sustainable planning process and the flexibility of its methodology through the application to a specific case study: the project “Casas de Sto. António”. This urban expansion project intervenes in a site lacking the existence of infrastructures or previous building, in the outskirts of a small locality - Sto. António da Charneca, located in the municipality of Barreiro. This site is included in Lisbon Metropolitan Area, presenting good accessibility to the highways A2 and A12, and placing itself next to the IC21, being also located next to the road of Mata Nacional da Machada.

In this project, it was intended to apply the previously presented urban process, in order to guarantee an equal treatment of all the sustainability components. Its program includes a compound of functions, mixing residential, commercial and equipment areas, on the basis of a strategy defined by the project team and the commercial promoter.

4.1. Intervention aims definition

In this stage, a joint of the sustainability basic principles and the recognition of specific goals for the intervention area must be established, based on the identification of local expectations. A table of programmatic principles was defined as the project's conceptual direction, in which the necessity to guarantee an equality of balance between the environmental, economical and social components is implicit for the intervention over the territory:

- Respect for the natural environment's charge capacity and safeguard of the ecological structure;
- Meeting the people's needs and expectations;
- Accomplishment of the requirements of the promoter, and of the project's economical sustainability;
- Execution of the urban parameters defined by the Municipality Master Plan [PDM] for the intervention area;
- Fulfilment of the infrastructures guidelines defined by the Municipality of Barreiro;
- Achievement of a greater use of public space, by an inductive urban design, including a continuous structure of free areas, and taking advantage of the site's natural elements;
- Outset of the program on the basis of a model of integrated project, with balance and complementarity of urban functions;
- Intervention according to the sustainable development and sustainable building concepts;
- Inclusive design of public spaces and fulfilment of the legal recommendations on accessibility for people with disabilities;
- Encouragement of the use of alternative transports to the automobile, and the creation of conditions for collective public transports.

4.2. Reference situation analysis

Aiming the identification of criteria with influence in the project's conception, in this stage it's possible and expected to elaborate a crossing table of all the elements potentially persuading urban design, the recognition of local weaknesses and potentialities and the definition of operative criteria of intervention. The recognition and interpretation of all the area's analysis and diagnosis factors are essential at this point, under the perspective of the complementary vectors of sustainability, considered in its whole diversity. The legal urbanistic constraints of the intervention area are also essential, so it is required to survey all the administrative servitudes and the applicable legal constrictions. In the case study, the following factors of diagnosis had been essential:

Environmental analysis:

- Identification of biophysical (geologic, climatic) and landscape features;
- Dominant winds and solar orientation;
- Levels of atmospheric pollution and noise;
- Recognition of biotopes, as well as landscape and environmental values - like the Mata National da Machada, forest area located southwest of the project's area, with its visual relations, and ecological corridors under the roadway;
- Identification of local species to protect in the area (spot of pines next to the south-western limit and isolated specimens of sobreiro – protected specie), and region's native species.

Economical analysis:

- Functional characterization of the area, including economic activity sectors and relative data about employment and mobility;
- Interdependence interactions with the involving areas.

Social and Cultural analysis:

- Demographic portrayal of the population, and relative data about lodging and house property, in the area's territorial statistic unit;
- Evaluation of availability and access to public and private equipment;
- Accurate knowledge about the needs and expectations of local population.

Urbanistic constraints:

– The Municipality of Barreiro Master Plan defines for the zone an urban occupation of average density, with limit of floor number.

4.3. Plan design

Plan design stage will have in consideration the goals previously defined for the intervention, as well as all the conclusions of the studies developed in the reference situation analysis. This stage comprises different actions, one of the most important being the definition of strategies and factors for the intervention's sustainability, framing the project in the concept lines of Sustainable Development. The case study's urban design plan had been taken into account options that reflect the concern about the intervention's sustainability factors.

The plan design proposal had the concern to preserve the identified biotope next to the southwestern limit with pine spots, strengthening the landscape and ecological interaction to the "Mata da Machada", and acting like an acoustic, visual and atmospheric pollution barrier to the motorway delimiting the southwest area of project's site. In this area, leisure activities and in touch with the natural environment was valued, installing an ecological pedestrian pathway, accessible both to local and of involving areas inhabitants. This solution, increasing the dimension of public spaces contributes also to the population's socialization.

The project's functional program was balanced, and foresees the inclusion of residential and commercial mixed buildings, as well as services and equipment areas, including a children's playground, articulating both economical and social features of the urban plan, aiming the satisfaction of the population needs and the quality of life. It also guarantees different housing possibilities to different social and economic stratus, promoting social cohesion and the economical sustainability of the intervention.

This project's planning design integrates the required connection between the process of sustainable planning and that of sustainable construction. In all conception of plan design is implicit the outline of buildings setting, thus being necessary to have in account the dominant winds and the solar exposition already in the urban project stage. Optimization of the available space was gotten, attending to:

- Solar exposure of property limits;
- Configuration of implantation polygon, its volume and number of floors - knowing that a compact building presents advantages in thermal exchanges, and that built volume shapes play important effects to ventilation and wind conduction patterns, as well to the chances of use of natural illumination;
- Land division's layout – location of buildings within property limits [isolated or stripe like], and streets traced according to solar and wind exposure;
- Creation of pedestrian pathways and public squares for all the intervention area..

Predefined urbanistic parameters of average density were satisfied, joining different densities, mixing buildings of plurifamiliar dwelling with several floors and areas of unifamiliar dwellings of low density, promoting greater diversity of urban and social space and reducing simultaneously the amount of waterproofed ground area.

Regarding the project's infrastructures, a system of pluvial water retention was foreseen, making possible a maximum tax of infiltration in the water cycle and simultaneously guarantying that the excess can contribute to the reduction of the public net dependence, as irrigation water of green spaces. Concerning hydrologic balance, it was considered the underground infiltration of pluvial waters, and its connection to the water lines of "Mata da Machada", aiming to reload the aquifer levels. The installation of the totality of infrastructures was coordinated and executed simultaneously under pedestrian pavement, to ease maintenance procedures and to prevent the partial reconstruction of the motorway.

4.4. Implementation

It is intended to guarantee that the final project proposal is efficiently implemented, respecting the predefined aims and giving fulfilment to the sustainability principles. All the implementation process is watched, evaluated and validated, in order that all the project's details and measures are effectively put in to practice.

During Construction stage, building options and procedures, as well as materials selection play an important role in the evaluation of the project's global sustainability. In the present sustainable urban process, it is given preference to local products, of low energy and water consumption, in its production or transport, preventing the use of non-renewable natural resources.

The implementation of an environmental management process is foreseen during the phase of project's construction. This acts as a guideline to the building work, prescribing procedures of environmental economy, like the reuse of materials waste in the composition of specific concrete works, and the existence of containers for recycling purposes.

It's equally foreseen the definition of measures regarding the phase of project's Use and Maintenance. The choice of constructive techniques and materials of high durability guarantees the extension of buildings and infrastructures life cycle, reducing the need of additional maintenance actions, and improving its sustainability. In this phase, it is also essential the definition and execution of applicable procedures to exterior spaces, concerning maintenance and use aspects, under the form of manuals and technical sheets.

5. CONCLUSION

The standard planning process over the last few decades, based in the strict application of urbanistic indicators and parameters, has shown its lack of efficiency in the implementation of the sustainability criteria, not taking care of the territorial specific characteristics or its load capacity, and not answering to the population's real needs. Only through a new planning process approach, it is possible to walk in the path of Sustainable Development. Given the diversity and specificity of the natural and urban environment, planning solutions must always be adapted to each case. Therefore, a sustainable urban planning process has to show an open and flexible methodology, always guided by the principles and strategic goals leading to sustainable development.

The presented Sustainable Urban Process, given its open structure, permits interventions on different realities and site dimensions, allowing to analyze the characteristics of each case, its potentialities, weaknesses and opportunities, guiding the project's planning process. The result of sustainable planning process will thus allow singular and differentiated urban solutions, taking care of all characteristics of local diversity and environmental sensitivity.

The application of this process to an existing case study turns evident, in terms of regulating and urban planning methodology, the advantages of sustainable planning process in comparison with the mere application of urbanistic parameters, introducing to urban space design a wealth of evaluation factors, and contributing this way to a greater sustainability of urban proposals. On the other hand, in "Casas de Sto António" project, the real execution of procedures allow us to verify the operational working validity of sustainable planning process, as well as all practical features included in the intervention's different phases and stages.

It is possible to conclude, that it is not through the widespread simplification of the planning process that it's possible to reach urban sustainability, but through a complete survey of all the features and site characteristics, as well as of an integrated analysis of all these factors supporting urban planning design. In this process, the population's involvement and the clear responsibilities of all the intervening actors are especially important, thus only this way it is possible to reach simultaneously the project's efficiency, promoting the improvement of population's quality of life, not compromising the future generations, and materializing a balanced treatment of all the Sustainability features.

REFERENCES

Amado, M. P. 2005a. Planeamento Urbano Sustentável. Lisboa: Caleidoscópio

Amado, M. P. 2005b. Operative Process in Sustainable Urban Planning. In A. G. Kungolos et al. (eds), *Sustainable Development and Planning* (1): 181-191. Londres: WIT Press

Banerjee, T.; Beessi, T.; Euguist, P.; Rahain, J. 2002. Is urban design on the eight track?, Places 15 (1): 81-84. California: University of Southern California.

Barnett, Jonathan. 2003. Redesigning Cities: Principles, Practice, Implementation. Chicago: American Planning Association.

Beatley, T. 2000. Green Urbanism, Learning from European Cities. Washington: Island Press.

Jon Lang. 2005. Urban Design: A Typology of Procedures and Products. Oxford UK: Architectural Press, Jordan Hill.

Sanoff, H. 2000. Community Participation methods in Design and Planning. New York: Jhon Wiley & Sons, Inc.

Slocombe, D. 1993. Environmental Planning, Ecosystem Science, and Ecosystem Approaches for Environmental Development. Environmental Management, Vol.17. New York: Springer New York.

Towards Urban Sustainability: Trends and Challenges of Building Environmental Assessment Methods

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ABSTRACT: Many countries have developed their own building environmental assessment methods or customized existing ones. International standardization is also underway to ensure a common framework.

These methods present some similarities in scope, intent and structure; yet they may differ substantially in many core aspects including the environmental criteria considered, the quantification of performance, and the management of the whole assessment process.

The present paper compares, both in form and technical content, a number of these systems (e.g. HQE®, BREEAM, LEED®, CASBEE, GBTool) with focus on their trends and perspectives and their capacity to move to the ultimate target of urban sustainability. This paper addresses the critical and current issue to know how to manage increasing complexity, i.e. induced by the extension from a single building to urban scale and by including the socio-economic dimension, together with ensuring more transparency, accuracy and reliability within simple assessment schemes.

1 INTRODUCTION

Numerous studies have been dedicated to building environmental assessment methods, either by comparing several methods or by analysing thoroughly one specific method (e.g. GBC). The focus was put alternatively on their relevance, content, initial and evolving intentions and roles, differences, perspectives, etc. (see e.g. Cole 2005). The author justly addressed a number of critical issues in the essence of such tools which are as many paths for re-thinking them. He states that current rating systems are facing the challenge to evolve in terms of simplicity, refining performance measures and indicators, improving verification methods, streamlining the certification process, the necessary support documentation together with their capability to manage more complexity in a simple and practical form. So, the present paper will not duplicate such studies but focuses on one of the most unaddressed challenging issues: The urban scale as new emphasis.

2 BUILDING ENVIRONMENTAL ASSESSMENTS METHODS

Prior to handle the urban issue, a brief review of the most mature and successful assessment methods was exemplarily undertaken, together with the French method HQE® tertiaire. These are the British, American, Japanese and international reference products, respectively: BREEAM, LEED®, CASBEE, GBC (GBTool). In the following analysis, the focus is put on the structuring of criteria because of their profound implications on the process and final evaluation of the building as an "ecological" product. A short statement of the convergences vs. divergences of these systems is drawn, with the ultimate task to commit a reflection whether it is relevant to extend these tools to urban scales and if so, how to achieve that goal. The review criteria were:

i. Applicability: Scope & Scale, Type of Project / Building.
ii. Development Approach: Intention, Update and Management of the method.
iii. System Maturity: Age, Stability, Representativeness, Versatility.
iv. Technical Content: Performance Topics, Thoroughness, End User, Aim of the tool, Decision Aid Means.
v. Communicability: Rating System's anatomy, Performance criteria's anatomy, Clarity.
vi. Measurability: Quantification, Benchmark, Weighting, Results Representation.
vii. Usability: Availability of Information, Assistance to user, Cost of assessment.
viii. Verification & Certification: The assessor, Required Documentation, Phases of assessment, Final Report & Certification.

Only a few of them are discussed here. More details are available from the author on request[1].

2.1 *Applicability: Scope and Type of projects and buildings*

The building is the main object of study of these methods. However, a noticeable trend for an extension to an urban scale is visible:

- The GBC takes into account explicitly the urban issue in one specific topic of its building assessment scheme i.e. "Site selection, project planning and development".
- HQE® and LEED® are developing new independent rating systems exclusively dedicated to the neighbourhood scale, i.e. *HQE aménagement* and *LEED-ND*.
- CASBEE : i) by extending comfort and well-being issues to the open spaces surrounding the building, ii) in CASBEE-H (where H refers to Heat Island) which is an adjusted version of CASBEE applied to large cities like Tokyo or Osaka, and iii) in "CASBEE for districts and regions" which is under development.
- "BREEAM Developments", on the other hand, provides an assessment framework to guide the sustainable design of developments, to allow developers to demonstrate the sustainability features of their proposals to the local planning authority.

At a national level, the building rating systems are differentiated depending on i) building type (residential, offices, schools, etc.) or on ii) the life phase of the building (planning, operation & maintenance, etc.):

– CASBEE differentiates between each phase of building life in form of Tools 0 to Tool 3 (pre-design, new construction, existing building, renovation), however all building types are taken into account in one tool.
– BREEAM handles all building life phases in one rating system; whereas each rating system is dedicated to one building type.
– LEED® portfolio includes i) rating systems for specific building types, and ii) for new and existing buildings.
– HQE® tertiaire approach is dedicated to tertiary activity including offices and educational buildings. Further tools are under development.

By contrast, the GBC (GBTool), which is exclusively academic and not commercial, has developed a generic system such, which explicitly recognizes regional specificities and offers a versatile possibility of use.

2.2 *Development Approach*

All investigated national rating systems (HQE®, BREEAM, LEED®, CASBEE) are commercial tools. They are more or less supported by their governments or private industry, sometimes within an academic frame. Their sensitivity to market imperatives explains the multiplicity of use-specific tools as mentioned above. By contrast, GBC is a primarily research project and by

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implication a voluntary tool. GBC suffers no limitations induced by marketing considerations.

For instance, the strong commitment of the industry and federal agencies in the LEED project, explains partly its rapid growth and expansion in comparison to other tools. CASBEE in turn clearly displays the aim of its implementation in Asia. This calls attention to the necessity of a careful analysis according to market contexts. BREEAM as well as LEED® are particularly effective in the management of their products thanks to numerous technical committees and in the latter case to the consensual approach based on the vote of the large LEED-membership.

2.3 *Technical Content and Management*

Figure 1 shows a comparison of the structure, i.e. the main topics of each of the environmental assessment methods under consideration. The two columns on the right side show respectively i) a summary of the analysed methods and ii) the draft proposed by the international Standard ISO under development on the subject.

Basically all these systems handle the major environmental issues of Energy, Water, Materials & Waste and Indoor Environmental Quality. However, differences are noticeable from one system to another in the consideration of the:

- Physical context (site, land use, open spaces, transport, etc.)
- Quality of service (Functionality, durability, long-term performance & maintenance, etc.)
- Human dimension in terms of social and economic aspects.
- Environmental loadings as main indicators of performance (greenhouse gases, pollution).

For example, BREEAM focuses on the environmental loading indicators favoured by the consideration of topics such as "transport", "land Use & ecology" rather than solely in terms of energy consumption. The HQE® approach is structured in 14 targets which is a more fragmented scheme in comparison to other systems, yet still covering the main performance issues. GBC is a more flexible tool and the successive versions may vary largely as can be noticed between GBTool 2000 and GBTool 2005 as no trademark stability concern exists.

CASBEE applies the recent ideas introduced by GBC 2000 of differentiating between the building as product and as services, by evaluating separately the environmental loadings on one hand and the quality of services on the other hand. CASBEE also pays more attention to the surroundings of the buildings and to socio-economic dimensions and hence initiates, at a national level, the extent of assessment boundaries to urban scale and sustainability matters as a whole.

The Management of the project involves more stakeholders than the only design team and requires an explicit commitment. This issue is included differently depending on the system:

- As a separate topic such in BREEAM, including all pre-design, construction, operation & maintenance.
- Included in the main topics of the rating systems such in LEED® (e.g. commissioning in the topic Energy). Yet, all management aspects are not taken into account.
- As a combination between a chapter “Environmental Management System: EMS” and single environmental targets (e.g. Targets 3 and 7).

2.4 *Communicability*

Two main types of structure were identified:

- A linear structure, as in BREEAM or LEED® where environmental performance is listed in form of individual checklists. Each of them consists of the aim or intent, awarded credits, compliance requirements and necessary documentation. This structure presents the advantage of clarity and ease of use.
- An arborescent structure as in GBC project, where the performance criteria are organised in a series of topics and sub-topics. First intended for versatility, this structure presents the disadvantage to be less transparent. Both HQE® and CASBEE are inspired from this model.

Comparative analysis of the structure of building environmental assessment methods											
Topics		**HQE®**	**BREEAM**	**LEED®**	**CASBEE-NC**	**GBC** **GBTool 2000**	**GBC** **GBTool 2005**	**Synthesis for the Building**		**ISO/TS 21931-1** (ISO / TC59 / SC17)	
Management	**A**	Env.Managt.Sys: EMS(*) Target 3 - Construction site Target 7 - Maintenance	M Management	distributed into the 4 main topics	Q2 Quality of Service	M Management (pre-operations) S Quality of Service	E Functionality F Long-Term Performance	Management [Commitment, Construction Site Operation & Maintenance]	Quality of Service	Building Management (+) Performance / Life Cycle	
Site	**B**	Target 1 Surrounding Environment	LE Land Use & Ecology T Transport	SS Sustainable Sites	Q3 Outdoor Environment on Site	Transport	A Sie selection, Project Planning & Development	Urban Design Transport	Sustainable Sites		
Indoor Environment	**C**	Comfort Targets [8, 9, 10, 11] Health Targets [12, 13]	HW Health & Wellbeing	IEQ Indoor Environmental Quality	Q1 Indoor Environment	Q Indoor Environmental Quality	D Indoor Environmental Quality	Indoor Environmental Quality		Indoor Environment	
Resource Consumption	**D**	Target 4 - Energy	E Energy	EA Energy & Atmosphere	LR1 Energy	R Ressource consumption	B Energy & Resource Consumption (Materials & Water)	Energy		Primary Energy Use	Waste production
		Target 5 & 14 - Water	W Water	WE Water efficiency	LR2 (Water) Resources & Materials			Water		Water Use	Land Use
		Target 2 - Products Target 6- Waste	MW Materials & Waste	MR Materials & Resources				Materials & Waste		Material Use	Local Impacts
Environmental loadings	**E**	*see* Target 4 Energy	Pollution + *see* Land use & Ecology		LR3 Off-Site environment	L Loadings	C Environmental Loadings	Environmental Loadings		Environmental Impacts	
Socio-Economic aspects	**F**				*see* Q3 Quality of Service	Economics	G Social & Economic Aspects	Social Dimension	Economic Dimension		
Creativity System's Openness	**G**			Innovation & Design process (Bonus points)				Innovation & Design Eco-Education, etc.			

(*) EMS : Environmental Management System
Dotlines state for issues which are implicitly taken into account or parts of other topics

Figure 1: Comparative analysis of the structure of building environmental assessment methods, together with the related ISO project

2.5 *Measurability*

All systems combine quantifiable and prescriptive criteria. All systems but HQE® tertiaire use a quantitative scale in form of cumulative points achieved for each performance criterion. In GBTool and CASBEE two partial totals are calculated which correspond to i) Quality and ii) Loadings, respectively. CASBEE reports a final score which is a ratio of both. This gives the possibility to a finer analysis of the building real impacts. A ranking or a building profile is then used to communicate final results.

In GBTool the interpretation takes into account the regional and local specificities, since the benchmarks can be managed separately by national teams, with the assessment system remaining identical. Several levels of weightings are also possible in GBTool. This issue is critical, yet variable from one system to another and confirms the relative value of the final results provided by each method. In order to guarantee the compliance to performance criteria, the verification means must be explicitly defined. Here, the British and American tools provide more links to decision-aid sources. As well, the clear formulation of the required documentation makes the assessment easier and more reliable. This latter point also suffers some divergences from one system to another. All these aspects are major improvement areas of these tools.

2.6 *Trends and perspectives*

The issue of sustainability assessment is strategic, either in Europe or at a wider international level. Most countries have developed their own tools or adjusted existing ones to their specific context. Yet, a common language is lacking, and several projects are underway which seeks to act as a common theoretical background for forthcoming methods. Figure 2 shows the two main frameworks presently under development: ISO/TC59/SC 17 and CEN TC 350 projects, together with one example of country local standards, i.e. France. These projects are still limited to the building scale.

3 SUSTAINABILTY ASSESSMENT AT AN URBAN SCALE

3.1 *A climate-conscious urban design method*

One main issue of increased complexity in assessment methods is the extension of their scope to urban context. The concern of sustainability of cities has focused the interest of several research fields for decades. Yet, the lack of a framework which coordinates all findings in readily understandable performance criteria prevents their effective implementation. Hence, the proposal of an "*urban sustainability assessment method*" inspired from existing building assessment methods is one way for bridging the gap between theory and practice at urban level, and between diverse disciplines on sustainability matters. The following material discusses some relevant points to build this new methodology.

The starting point in building environmental design (1970's) was the concern for optimising the use of natural energies, the so-called bioclimatic architecture. Later in the assessment methods, the importance of energy is confirmed by its high weighting (For energy criteria: BREEAM 15 points, LEED® 10 points and HQE® high or very high level).
Similarly, at urban level, the first attempts for structured design methods also dealt primarily with the climate and energy, see e.g. Ali-Toudert (2000) for a review of published methods. This is because of the critical issues of energy savings, human comfort, health and safety issues, all related to the availability of solar and wind access which are compromised by the urban density and to the formation of particular urban microclimates, etc. For instance, Ali-Toudert (2000) proposed a conceptualized methodology for integrating the climate in urban planning and urban design.

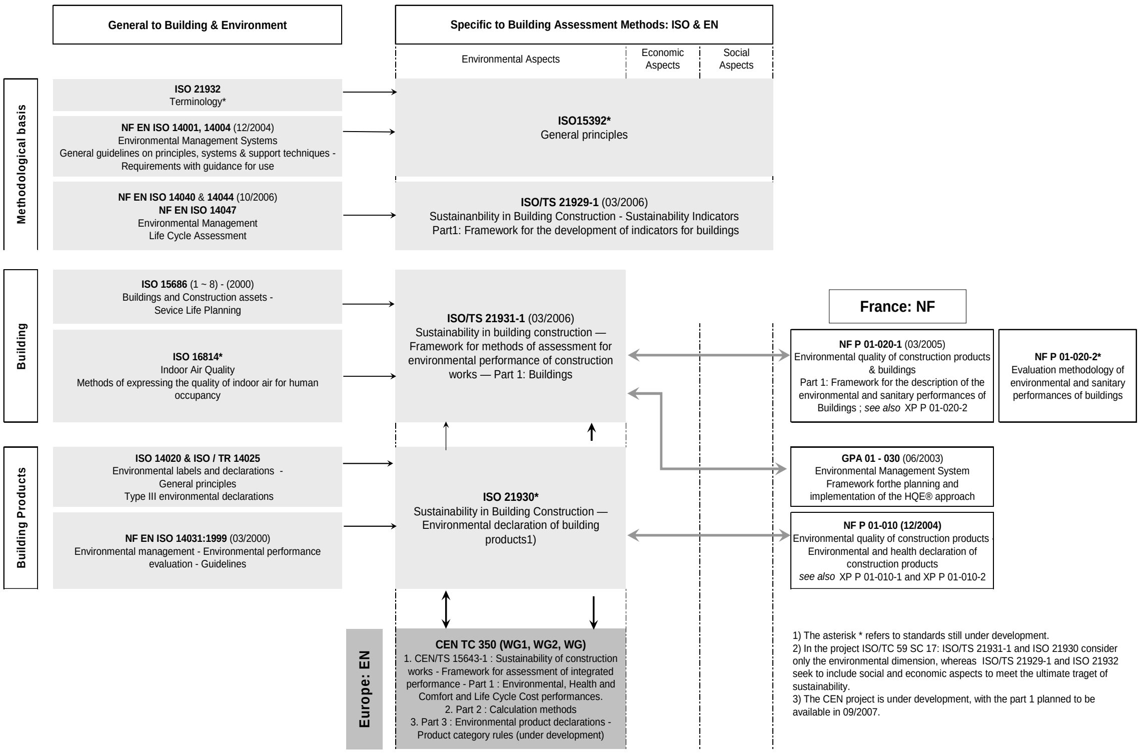

Figure 2: Standardization of environmental issues applied to the building: ISO - EN – NF

1. Urban Planning :
   i. *The Climate* at regional & local levels to determine the basic design recommendations.
   ii. *Site Selection* to gain the optimal advantages from appropriate urban locations.
   iii. *Urban Permeability* (to wind) to keep connection with the natural environment and energies, and avoid the overheating of the city (Urban Heat Island UHI mitigation).
   iv. *Land Use* in terms of integration versus segregation of activities (residential, working areas, leisure, industry, etc.)
   v. *Landscaping* which summarizes the positive effects of green at a large scale.
   vi. *Urban geometry* as a link to the next design stage, as follows:

2. Urban design :
   i. *Openness to the Sky* for solar and energetic control, i.e. to ensure solar access / protection.
   ii. *Urban Porosity* which governs the ventilation rates in the urban spaces and hence indoors.
   iii. *Directionality* which discusses the optimal orientation of the street and buildings according to solar and wind needs.
   iv. *Urban Reflectance* which governs the heat storage potential in the urban fabric: Buildings & surfaces (UHI mitigation)
   v. *Building Envelope* which acts as an interface between architectural and urban design strategies:
   vi. *Urban Vegetation* which explains how the green may be the most useful for enhancing human comfort and energy savings.

At design scale, the focus was put on geometrical indicators to ensure operative guidelines. These have been refined in a later research (Ali-Toudert 2005).

3.2 *Towards an Urban Sustainability Assessment Method*

The interest for sustainable cities as a generic keyword is manifold and combining all information sources for elaborating new appropriate rating systems is necessary:

1. The so-called environmental urban architecture, mainly supplied by architects and urban designers, and which progressively extends its physical limits (see e.g. Thomas 2003).

2. Urban climate research which provides tremendous information on the specific climate of urbanized sites and especially the urban heat island which is the main expression of climate change. These findings rely on a strong physical basis.
3. The current design practices where practitioners and other stakeholders try to extend “intuitively” building assessment methods to urban neighbourhoods by paying more attention to building’s surroundings.

As previously mentioned, some attempts are made to bring on the market rating systems which scope is the neighbourhood or even the city as a whole, e.g. LEED-ND. Yet, these tools are in an experimental stage and need verification and feedback.

To give a picture of such an approach, Figure 3 is a proposal of a basis structure for a sustainability assessment method at an urban scale.

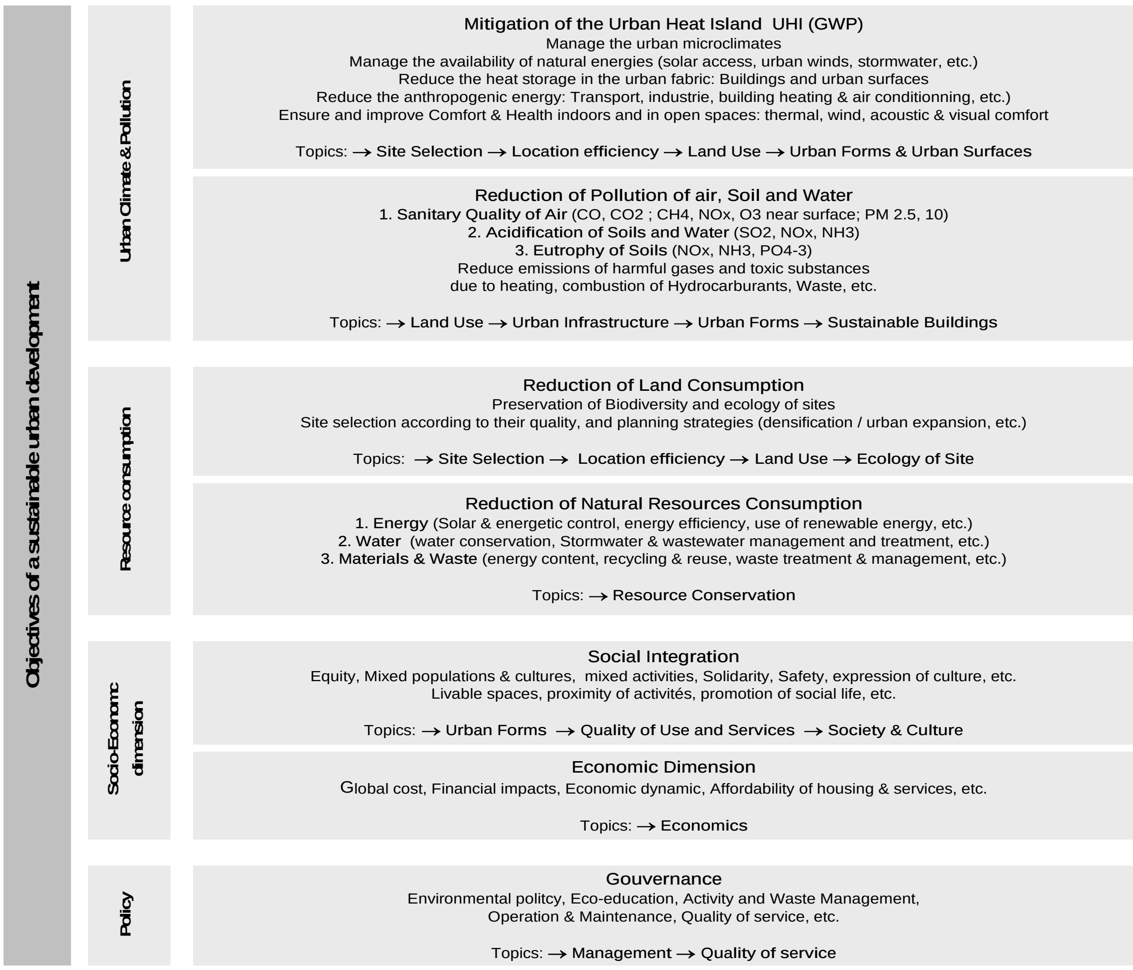

Figure 3: A framework for an urban sustainability assessment method

Basically, there will be continuity and no rupture on an environmental level, while moving from building to urban scale assessment, because the indicators of environmental loadings are identical: global warming potential GWP, Resource Consumption, Ozone depletion ODP, Pollution of air, soil and water. Hence, the major topics applied to environmental building assessment are expected to be reused at urban level, such as the efficiency in energy or water resources use. Yet these topics need to be addressed differently according to the specificity of the current object of interest: the “urban fabric”. The content will be revised according to a number of major differences:

1. The object « city » consists of indoor spaces (buildings) and open spaces (streets, places and parcs): Both are living spaces and support human activities, which require a high environmental quality, as well as they both effect more or less negatively the environment.

2. The urban climate and more precisely the urban heat island (UHI) is the main phenomenon characterizing the city from an environmental point of view. Consequently, a key issue for implementing a powerful assessment method at urban scale is to understand the mechanisms which lead to the formation of the UHI together with their dependence on planning and design choices.
3. The consumption of land as precious resource takes here a much more dominant place in comparison to building scale, since the site selection as well as the whole land use strategy relies on the availability of land (expansion, densification, infrastructure, etc.) These in turn will affect the need for other natural resources such energy, water or materials.
4. The social and economic dimensions assume an important role, since the city is by definition an organized framework for human activities and a concentration of capitals. This means that an extension of performance assessment to urban level extends automatically its limits beyond the environment to include all sustainability issues.

A number of topics can be pre-defined as a working basis:

– *Site Selection*, *Location Efficiency*, *Land Use* and *Ecology of Sites*: to avoid hazardous locations, improve site and climate quality, and preserve ecosystems.
– *Urban forms & Surfaces*, *Urban Infrastructure* and *Sustainable Buildings*: which include the optimisation of urban density, street network and pedestrian areas, Building forms and arrangements, an integrated community development, based on diversity and a balanced mix of activities, proximity Work/ Habitat, etc.
– *Quality of Life* including the *Human Wellbeing & Health*, *Social & Economic integration*.
– *Conservation of Resources*: Land, Energy, Water, Materials and Waste.
– *Management* and *Quality of Service* including commitment and eco-education, construction, operation and maintenance.

4 CONCLUSION

Building assessment methods offer a good basis for elaborating new a scheme for urban scale assessment. Yet, attention must be called to some precautions, already observed at building level, from which the necessary clarity and accuracy in quantitative assessment, scoring, context specificities, double counting, as well as a careful definition of the prescriptive criteria related to qualitative issues, etc. It is essential to offer systems that serve as a common framework for all stakeholders, and particularly to design teams which face the great challenge to manage conflicting design issues and manifold interests. Moreover, a distinction between performance assessment and market interests is also important. Indeed the latter might effects negatively the objective and rigorous setting of performance criteria and scoring. A multidisciplinary work is essential to build this method and a close collaboration between all environmental fields, urban climatologists and planners/designers is crucial.

5 REFERENCES

Websites of the reviewed assessment methods: HQE®: www.assohqe.org ; LEED®: www.usgbc.org/LEED ; BREEAM: www.breeam.org/ ; CASBEE: www.ibec.or.jp/CASBEE ; GBC: www.iisbe.org/iisbe.

Ali-Toudert, F. 2000. Integration of the climatic dimension in Urbanism. Master thesis. School of Architecture and urban design EPAU. Algiers.

Ali-Toudert, F. 2005. Dependence of outdoor thermal comfort on street design. PhD thesis. *Rep. Meteor. Inst. Univ. Freiburg No. 15*. http://www.freidok.unifreiburg.de/volltexte/2078

Cole, R. 2005. Building environmental assessment methods: redefining intentions and roles. *Building Research and Information* 35, 455-467.

Thomas, R. 2003. Sustainable urban design - an Environmental approach. Spon. London.

Green cities of tomorrow?

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ABSTRACT: In this article solutions are sought for turning cities into more sustainable spaces, by mitigating their heat island effect. The factors which affect the formation of the heat island effect are discussed briefly, followed by the solutions proposed by the 20th century visions of the utopian cities. With vegetation being a key factor in all 20th century urban utopias, this paper investigates to what extend and in which form vegetation in cities could turn them into more sustainable spaces, focusing on the thermal effects of vegetation and its effects on the energy consumption for cooling as well as on the improvement of thermal comfort in urban spaces.

1 INTRODUCTION – THE HEAT ISLAND EFFECT

Following the rationale that a sustainable unit is a unit which uses no more than it can replace, many of the commodities in existing cities should be rethought and redesigned. Apart from recycling, lowering the energy demand of cities and especially the one consumed in buildings is a crucial step for making cities more sustainable. Especially urban dwellings tend to consume more energy for cooling than suburban or rural dwellings, due to the heat island effect, a climatic phenomenon caused by the environmental alterations of modern cities.

The main differences between an urban and a rural environment are governed, in general, by altered factors which affect heat exchanges in a local scale. Factors such as optical and thermal properties of materials (albedo, emissivity, heat capacity) are of different magnitudes for materials in rural and urban areas. In addition, urban areas are characterised by the lack of evapotranspiring surfaces (vegetation) and materials of low porosity. The geometry between a vegetated area and the density-morphology of an urban area are completely different, which has a direct effect on wind and shade distributions. Human activities taking place in urban areas are responsible for anthropogenic heat release (transport, space and water heating, cooling etc) and air pollution, the latter affecting cloud cover. The combination of these factors determines the way in which heat is absorbed, stored, released and dispersed in the urban environment, expressed as a temperature increase in the urban area.

All these altered factors lead to new energy balances in urban areas, which result in different air temperature distributions in the urban areas. It can be said that, in general, the differences of the air temperature between urban and rural area, regarding distance, for a large city with clear sky, exhibit a steep temperature gradient to the centre of the urban area, forming an “island profile” (Oke, 1987). The temperature difference between the urban and rural environments is called the *heat island intensity* and it is an indicator of the magnitude of the heat island effect. It is usually calculated from the maximum urban temperature at the canopy layer and its respective rural temperature and varies, according to the characteristics of the city and its population. Chandler (1965), when examining the heat island effect of London came to the conclusion that there were more days with exceptionally high temperatures and fewer days with lower temperatures in the city centre. The estimated London heat island density is of the magnitude of +1.4^{o}C (ibid). For the hotter climate of Athens and its greater absence of vegetation the heat island effect becomes larger, reaching the magnitude of +10^{o}C (Santamouris, 2001).

In cold climates the heat island effect may influence beneficially the heating energy demand of buildings (Givoni, 1998). As higher ambient air temperature is produced, less energy is required for heating. However, due to global warming becoming a sensitive issue over the last few years, this perspective has changed. It is estimated that the combination of global warming and the heat island effect of London might be responsible for more energy being expended for cooling the city than the energy saved for heating and that it could also lead to a parallel increase in summer stress and mortality (Clarke et al., 2002). In cities in lower latitudes, such as the Mediterranean area, the heat island effect has proved to be disagreeable, both from an energy consumption and a quality of life point of view.

For warm and hot climates, the resulting higher temperature can lead to increasing demands for air-conditioning during hot period which exceeds by far the energy savings in winter and may cause unbearable levels of heat stress. Due to the heat island effect, the cooling degree hours in the central area of Athens are approximately 350% greater than in the suburban areas, while the heating degree hours are only 40-60% less (Santamouris, 2001). Rosenfeld et al. (1995) observed that in American cities for each 1^{o}C rise in daily maximum temperature above a threshold of 15^{o}C to 20^{o}C, the peak urban electric demand rises by 2–4%. The additional use of air-conditioning caused by this urban air temperature increase is responsible for 5–10% of urban peak electricity demand. The use of air-conditioning for cooling buildings removes the heat from the building to the urban environment. In very dense areas with excessive use of air-conditioning systems this leads to a significant rise of the ambient air temperature (Papadopoulos, 2001), and thus to a rise of the cooling demand, leading to a vicious cycle of rising the ambient air temperature and energy demand.

This extensive need for cooling energy leads to increasing emission of pollutants from power plants and air-conditioning systems such as sulphur dioxide, carbon monoxide, nitrous oxides and suspended particulates. Especially in cities with hot climates, during summer, this combination of extreme temperatures and pollutants can even be responsible for high rates of morbidity and mortality risks, especially respiratory-related mortality, cardiac arrests, stroke, and a variety of direct heat-related illnesses (Kalkstein and Sheridan, 2003). With the future climate change expecting to increase the number and intensity of extreme events, such as heat waves, and increased maximum and minimum temperatures (White et al., 2001), urban dwellers are bound to suffer from excessive heat stress. With most deaths caused by heat waves occurring in urban centres (Koppe et al., 2004; Kalkstein and Sheridan, 2003), urban populations health is bound to be at risk (White et al., 2001; Koppe et al., 2004). The heat waves experienced in Europe in 2003 cost the lives of 14,603 people in France and 3,134 in Italy (Koppe et al., 2004). It has been reported that the 10-day heat-wave in Athens in 1987 resulted in 926 deaths classified as heat-related, while the attributable excess mortality was estimated to be more than 2000 (Koppe et al., 2004).

From studies made in the United States, regarding the effect of reducing the heat island effect on mortality risks, it has been estimated that a 0.5-1.0^{o}C reduction in outdoor temperature, in combination with other meteorological changes, could reduce urban mortality by 10-20% (Kalkstein and Sheridan, 2003). Apart from energy saving and quality of life, when human life is put under such risk due to the heat island effect, it is impossible to discuss about sustainability in today cities, unless these raised temperatures are mitigated. With the absence of vegetation being one of the most important factors affecting the formation of the heat island effect, the introduction of vegetation in urban life is a promising solution for more sustainable conditions of living in the cities. With vegetation being a primary concern in most 20th century utopian city visions, as examined below, vegetation could become the element that would relief 21st century cities from raised temperatures and turn cities into more sustainable and human spaces.

2 URBAN VEGETATION IN 20TH CENTURY UTOPIAS

Even before the burst of the Industrial Revolution, with the revival of cities in the Renaissance, utopians were dreaming of urban spaces where vegetation would not be a privilege, but a right. Thomas More, in 1516, the inventor of the word *"utopia"*, dreamt of the ideal capital, where all houses would have large, back gardens in which *"vine, fruits, flowers and any kind of plants"* would be cultivated by the inhabitants (More, 1989). One of the most influential utopians of the 20th century city planning was Ebenezer Howard, who expressed the necessity of vegetation on an urban scale with his idea of “garden cities”, which would play an important role around the globe as a solution to the problems of industrialised cities and influence the urban planning of the first quarter of the 20th century around the globe (Kafkoula, 1990). In its strict definition the term “garden city” describes “*a town designed for healthy living and industry; of a size that makes possible a full measure of social life, but not larger; surrounded by a rural belt, the whole of the land being in public ownership or held in trust for the community*” (Lancaster and Slaughter, 2000). Howard’s garden city theory envisioned a planning system where the pros of both urban and rural environments could be combined. To the concentrated vast city, he proposed an alternative social city with a network of garden cities with their own industries, around a slightly larger, central city. His principles were the conscious control of the size of towns, the existence of large parks in the city and gardens adjacent to houses, farmlands surrounding the urban areas, and communal land ownership, in order to protect the living environment from individual interests and profits (Howard, 1970). In this way cities would be sustainable, consuming no more than they could replace and human, with vegetation, the privilege deprived from working classes in London, becoming the right of every citizen. Visioning small cities with low-rise buildings and large open, green spaces, he never considered it a necessity to put forward the idea of covering buildings with vegetation, as utopians who dreamed of larger-scale cities did.

Apart from Howard, greenery in the city was a central element to Frank Lloyd Wright’s urban planning visions. From an individualist perspective, he conceived and proposed the ideal city of Broadacre, in 1935, where buildings and the city they composed disappeared into nature. In a much more decentralised concept than Howard’s garden city, in Broadacre, there was no planning distinction between the built and the natural environment, with vast distances between individual buildings, covered by highways. Without any spatial distinction between rural and urban life, Broadacre City achieved a no physical distinction between the two. With buildings “lost” into nature, in his model of the Broadacre City, some buildings completely disappeared into nature, having their roofs and terraces covered in green (De Long, 1998).

Le Corbusier, on the other hand, was extremely critical to Howard’s “horizontal” garden cities and proposed instead “vertical” garden cities. With his great belief in the “Machine Age” and the spatial instability that “mechanised speeds” had introduced, he suggested that society was becoming “nomadic”, making the settled stability of the family house of low rise “horizontal” garden cities, an echo of the previous era. Instead, his “vertical” garden cities could be applied, which were composed of “superimposed” apartments in elevated, Dom-Ino type skyscrapers, in the middle of parks. In this way, dwellers would be overlooking a garden from their homes, instead of roads and vehicles. Le Corbusier had incorporated these ideas into his Contemporary and Radiant City. In his Contemporary City, in 1922, he proposed “vertical” garden cities within the centralised city for the ruling elite to work and live and “horizontal” ones in the outskirts for the labouring class. Each apartment of the elite skyscraper dwelling had a green veranda, a “hanging garden” as he called it. The roofs of the office skyscrapers were green, gardens for the elite’s entertainment at night. The outskirts where the labouring classes would be kept, would consist of smaller building apartments, also surrounded by gardens, where entertainment for the workers could be found. Green roofs and vegetation on buildings were not placed on the residences of the working class; only in the dwellings, work and entertainment buildings of the ruling class. The working class dwellings had a detached relationship to nature (seeing it in the park next to them, but not on the building itself). Eleven years later, the social structure of his Radiant City changed dramatically. For a city organised around syndicates, Le Corbusier now proclaimed that *“if a city were to become a human city, it would be a city without classes”* (Fishman, 1982). Nonetheless, vegetation on buildings and surrounding buildings remained a central element in his visions and he exclaimed that nature should be brought into the cities themselves, creating the *“Ville Verte”*, the “Green City”. Doing away with streets, his high-rise apartment blocks, now called “*Unités*”, surrounded by parks and gardens as in the Contemporary City, were designed now for every citizen of the unstratified society of the new civilisation in the Radiant City. The roofs of the *Unités* were covered with gardens, for the inhabitants’ recreation. For the right of every urban dweller to vegetation he exclaims *“flowers… for all of us!”* (Le Corbusier, 1933).

It has been argued that utopias cannot be even a partial guide to achieving a sustainable city, as most of them describe isolated, ideal, static places and conditions which are generally unrealistic. Nonetheless, utopian visions can be useful inspiration, when trying to move in that direction (Blassingame, 1998). As has been observed, vegetation has been a crucial element in utopian city planning of the Industrial era. Either in the form of buildings lost in nature, or in numerous parks within the city or on the roofs of urban buildings, vegetation has been perceived as the vehicle through which nature and man are re-united in the Machine age, under more human and for some utopians, more sustainable urban spaces. In the following paragraphs this sustainability of either mixing vegetation in cities in the forms of parks, or covering the building fabric itself, is examined how sustainable it could be, from a thermal point of view.

3 URBAN PARKS FROM A THERMAL POINT OF VIEW

Although urban parks can be extremely beneficial for a city from a social and city planning point of view, from a thermal point of view they can mitigate the heat island effect only at their micro or meso scale, rather than the local scale of the city. The air temperature is reduced significantly inside the park, but only the few buildings in the neighbouring area of the park can benefit from this reduction of the air temperature. The rest of the city is not affected thermally by the presence of the park. This has been proved both theoretically and through in situ measurements and experiments.

Measurements carried by Santamouris et al. in parks in the centre of Athens in the summer of 1998, showed that the air temperature inside the park is significantly lower than for the densely built city centre, with a peak temperature difference in the afternoon, of the magnitude of 13^{o}C. They pointed out that temperatures in these parks present almost 40% fewer cooling degrees hours than their surrounding urban stations (Santamouris, 2001). It was also found that air temperature around the park is mainly influenced by parameters other than the presence of the park, such as the density of buildings, the rate of anthropogenic heat release, the shading of canyons and so forth (ibid.) and not so much by the park itself. Similar effects for the climate of Athens have been perceived by the computational modelling carried out by Dimoudi and Nikolopoulou (2000). Through their study they also showed that the buildings which could experience thermal benefits from the existence of a park were only those which were contiguous to it. Heat stored on the buildings’ fabric affects the cool air of the park, raising the ambient air temperature sharply (Dimoudi and Nikolopoulou, 2000).

In the tropical hot and humid climate of Dhaka, Bangladesh, measurements were carried out by Ahemed in different urban layouts of the city. It was found that 300m away from a large park of a high-density modern built part of the city (the Motijheel commercial area) there was practically no cooling effect from the park. On the contrary at the Ramna area, which is characterised by low density, mature trees and a fairly high distribution of vegetal covering in general, air temperature in these urban canyons was noticeably lower because of the existence of vegetation (Ahemed, 1995). Ahemed came to the conclusion that for tropical climates a number of small parks in an area of the city can be more effective in moderating the microclimate of the area than a large park. Giridharam et al. (2004) when evaluating the heat island effect in residential high-rise and high-density areas of Hong Kong also came to the conclusion that pockets of green area are more advisable for mitigating the heat island effect than a single large green area.

With the existence of an urban park, the heat island effect is therefore moderated quite locally, basically inside the park and at its surrounding buildings. A local oasis is formed, but only in the core of the park and its immediate surroundings. The rest of the buildings and the city itself remain practically unaffected by the presence of the park, from a thermal point of view. Urban parks can have a quite important effect on the urban air temperature if they are spread across the city and they are quite densely placed (Dimoudi and Nikolopoulou, 2000; Ahemed, 1995; Giridharam et al., 2004). From a thermal point of view, parks within a city could thus be paralleled to oases in the desert; no matter how many oases there are, the temperature is still high in the desert, away from the oases. Numerous oases could have a larger thermal impact on the desert enclosing them, but they could not lower its temperature as much as if they were mixed with the desert. Although this cannot happen in the desert, it can happen quite easily in existing cities, by covering their impermeable, hot surfaces, such as the walls and roofs of buildings, with vegetation.

4 URBAN GREEN ROOFS AND WALLS FROM A THERMAL POINT OF VIEW

With the use of a two-dimensional heat and mass transfer model (Alexandri, 2006) the thermal effect of vegetation and its evapotranspiration has been described in detail for the environment of an urban canyon, whose roofs and walls have been covered with vegetation. The results of this study are discussed in the following paragraphs.

4.1 *Comparison of the Thermal Effect of Green Roofs and Green Walls*

In summer the hottest areas of the canyon, especially after midday, are the roofs, which absorb large amounts of solar radiation. When the roofs are covered with vegetation the hottest areas after midday is the street surface. In figure 1 a summary of the air temperature distributions in and above the canyon and the roofs is given for Montréal and Mumbai at 18:00 of a typical day of their hottest month (July for Montréal, May for Mumbai). It can be observed that green walls and green roofs can mitigate air temperatures quite significantly in and above the canyon. On the one hand, when only the roofs are green, there is no significant thermal effect inside the canyon, apart from its upper layer. On the other hand, when only the walls are green, they do not affect temperature distributions at roof level. Thus, if the aim is to lower temperatures at an urban scale, green roofs should be applied. In case the aim is to lower temperatures at a building scale, green walls should be considered. Nonetheless, the combination of both green roofs and green walls can prove beneficial not only for lowering raised temperatures at both the roof and the urban level, but also for lowering temperatures inside the urban canyon, as can be observed in all the c cases.

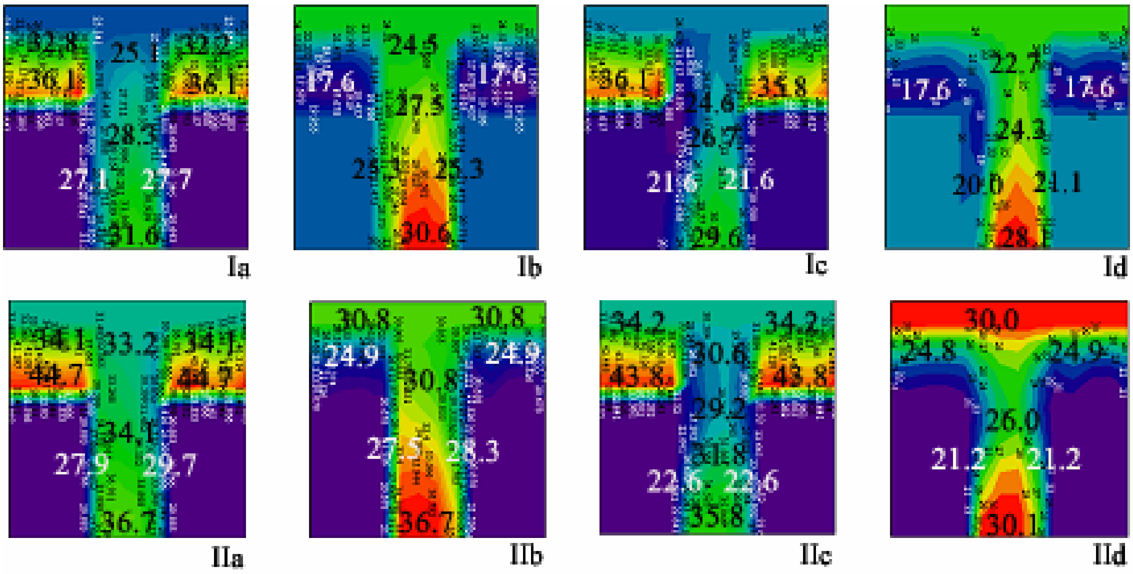


Figure 1. I) Montréal and II) Mumbai temperature distributions inside and above the EW-oriented H5W10 canyon for a) a canyon without any vegetation, b) a canyon with green roofs, c) a canyon with green roofs and green walls, and d) a canyon with green walls, at 18:00 of a typical day of their hottest month (July for Montréal and May for Mumbai) (author)

4.2 *The Effect of the Climate*

The effect of green roofs and walls has been investigated for nine cities in nine climatic zones (figure 2). It has been observed that the hottest and driest a climate is, the largest the effect of green walls and green roofs on mitigating its urban temperatures is. For all the cases examined, Riyadh is the hottest and aridest climate, reaching a temperature decrease inside the canyon of 11.3°C maximum and 9.1°C day-time average when both roofs and walls are green. Equally hot, but much more humid Mumbai reaches smaller decreases, of the magnitude of 6.6°C day-time average and 8.0°C maximum. The colder climates of London, Moscow and Montréal benefit the least, reaching from 3.0°C to 3.8°C for the day-time average decreases and from 3.6°C to 4.5°C, respectively, for the maximum.

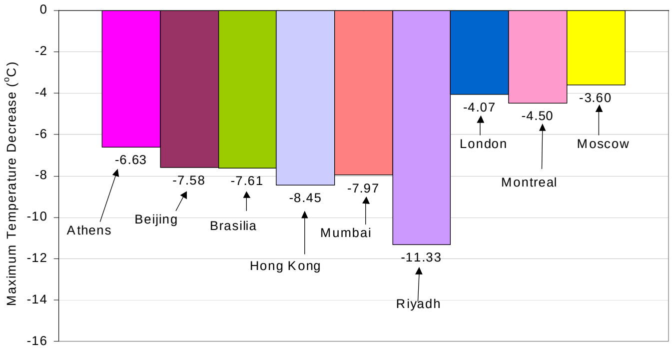


Figure 2. Maximum temperature decreases inside a canyon, for the case where both roofs and walls are green, for the climates of: Athens (Mediterranean), Beijing (Steppe), Brasília (Savanna), Hong Kong (Humid subtropical), Mumbai (Rain forest), Riyadh (Desert), London (Temperate), Montréal (Subarctic), Moscow (Continental cool summer) (author).

4.3 *The Effect of the City Geometry*

There are also other factors affecting the effect of green roofs and walls on the heat island effect, such as the canyon geometry, orientation and relation to wind direction.

The wind direction plays a not so important role on the thermal effect of green roofs and walls, as wind velocities within the urban canyon are not so high, making the effect of wind direction not so strong on the temperature decreases due to vegetation (Alexandri, 2006).

Canyon geometry plays the most important role in the thermal effect of green roofs and walls. Although the canyon orientation may play a more important role in latitudes away from the Equinox, where different amounts of irradiation are received from different orientations (Alexandri et al., 2005), the most important role is that of the relationship of the building height (H) to the street width (W). In general, it can be observed that the wider a canyon is, the smaller the effect of green roofs and green walls on it. For wider canyons, temperatures inside the canyon are dominated by the proportionally larger street surface and the fact that it is more exposed to direct solar radiation. In the instance of different ratios of building height to street width (H/W) for the climate of Athens (figure 3), it can be observed that the temperature decrease in the wide canyon with 0.33 ratio of building height to street width (H/W) are of the magnitude of 4.2°C for the day-time average and 5.9°C for the maximum. For the narrower canyon, with 0.50 ratio, the effect of green buildings is more apparent on temperature decreases, with temperature decrease of 5.6°C day-time average and 6.6°C maximum. For the narrowest canyon examined, where wall height is more dominant than street width (H/W=2.00), the temperature decreases are much higher, reaching 5.3°C for the day-time average and 8.3°C for the maximum.

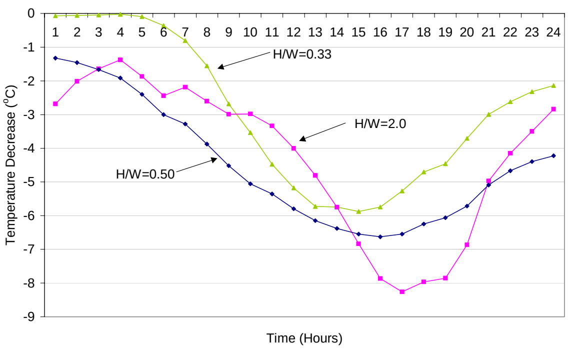
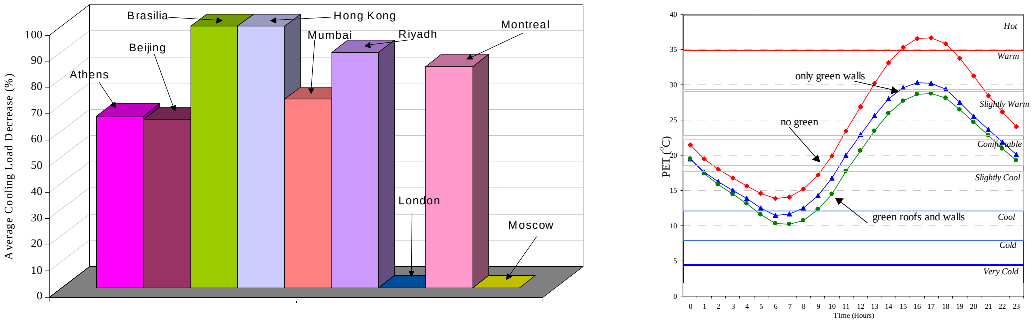


Figure 3. Air temperature decrease in canyons with different ratios of building height to street width (H/W) when both roofs and walls are covered with vegetation, in Athens, in July (author)

4.4 *Effects on Energy Consumption for Cooling*

These lowered summer temperatures can only have a positive effect on lowering urban electricity needs for cooling spaces and setting the basis for more sustainable cities. Considering an indoor limit temperature for cooling of 23°C for all climates studied, the cooling load decreases in both cases when only the walls are covered with vegetation and when both roofs and walls are green. As can be observed in figure 4a, the largest cooling load decreases in all climates examined, occur when both roofs and walls are covered with vegetation. For the geometries examined for Brasília and Hong Kong, the cooling load decrease reaches 100%; no cooling load is needed after covering roofs and walls with green. London and Moscow are not affected at all, regarding the cooling loads, as no cooling load was needed for the typical day examined, even before vegetation was placed around the canyon. Riyadh experiences a quite high cooling load decrease, of the magnitude of 90%, as does Montréal (85%). Mumbai reaches a 72% decrease, while for Athens and Beijing the decrease is 66% and 64%, respectively. In general, green roofs and green walls cool the microclimate around them, which can lead to quite important energy savings from cooling, depending on the climatic type, the amount and position of vegetation on the building. In cases where little cooling load is needed, cooling demand can be reduced to zero by covering the building surfaces with vegetation. In addition to the energy savings themselves, this could lead to successful applications of further passive cooling techniques, especially ones employing ventilation, which are not easy to implement in extremely hot urban conditions.



a b

Figure 4. (a) Average cooling load decreases (%), with a 23°C indoors temperature, when both roofs and walls are covered with vegetation and (b) Physiological Equivalent Temperature inside a canyon without any vegetation (no green), when only walls are covered with vegetation (only green walls) and when both roofs and walls are covered with vegetation (green roofs and walls), in Athens, in July (author)

4.5 *Effects on Outdoors Thermal Comfort*

Thermal comfort in the city is also very much improved, when the building surfaces are covered with green. As can be observed in figure 4b, a man standing in a canyon without any vegetation, in Athens, for a typical day in July, is for 4 hours in the “hot” zone, for 4 hours in the “warm” zone and for 5 hours in the “slightly warm” zone. He is in the “comfortable” zone for only 3 hours and for 7 hours in the night is he in the “slightly cool” zone. When both roofs and walls are covered with vegetation thermal comfort in the urban canyon improves dramatically. Neither the “hot” nor the “warm” zone are reached. The “slightly warm” zone is reached for 8 hours and “comfortable” for 4. Again, in the early morning and night hours “slightly cool” and “cool” zone are reached for 6 and 5 hours, respectively. These temperature decreases due to vegetation, which move thermal sensation to more comfortable levels, can only lead to healthier urban environments with limited morbidity and mortality risks due to raised urban temperatures.

5 CONCLUSIONS

The utopian vision of mixing city with nature through vegetation has proven to be of the few sustainable paths towards cities whose dwellings consume less for cooling. Parks may be important spaces from a social and urban planning point of view, but from a thermal point of view, they can relief the raised urban temperatures only locally, without affecting the rest of the city, its raised energy demand for cooling and its uncomfortable summer thermal conditions. Creating the appropriate number of smaller parks for lowering urban temperatures, may prove unrealistic, due to the land use and values within cities. By not trying to create new ground-level parks, but by placing vegetation in the already available, vacant urban surfaces, such as roofs and walls, not only urban dwellers can have the right to vegetation of which most utopians were dreaming, but urban raised temperatures can lower by 11.3^{o}C to 3.6^{o}C in summer, depending on the climate and the urban geometry. Such temperature decreases can only improve the outdoors thermal comfort, which has a direct effect on the quality of life of urban dwellers, lowering the morbidity and mortality risks they face due to raised temperatures. Apart from that, the energy savings from cooling are quite significant, which may reach 100%, making the goal of sustainability a more attainable one for modern cities. If we want the 21st century cities to become sustainable, when their climate and geometry is appropriate, their buildings should be covered with vegetation and thus be transformed into the green cities of tomorrow.

REFERENCES

Ahemed, K.S. 1995. *Approaches to bioclimatic urban design for the tropics with special reference to Dhaka, Bangladesh.* London: Ph.D. Dissertation. Environment & Energy Studies Programme. Architectural Association Graduate School.

Alexandri, E. et al. 2005. Statistical analysis of the benefits of green roofs and green walls for various climates. In *PLEA2005 Beirut, Lebanon, 13-16 November 2005.*

Alexandri, E. 2006.Green roofs and green walls: could they mitigate the heat island effect? *MADE 3*:60-67.

Blassingame, L.1998. Sustainable cities: oxymoron, utopia, or inevitability? *The Social Journal* 35(1):1-13.

Chandler, T.J. 1965. *The climate of London*. London: Hutchinson & Co.

De Long, D.G. (ed) 1998. *Frank Lloyd Wright and the living city.* Milan: Skira Editore.

Dimoudi, A. & Nikolopoulou, M. 2000. *Vegetation in the urban environment: microclimatic analysis and benefits.* PRECis Project, the European Commission, Directorate General XII, Joule III, Contract JOR3-CT97-0192. Athens: Centre for Renewable Energy Sources.

Fishman, R. 1982. *Urban utopias in the twentieth century.* Massachusetts: The MIT Press, Cambridge.

Giridharam, R. et al. 2004. Daytime urban heat island in high-rise and high-density residential developments in Hong Kong. *Energy and Buildings* Vol 36: 525–534.

Givoni, B. 1998. *Climate considerations in building and urban design*. New York: Van Nostrand Reinhold.

Howard, E. 1970. *Garden cities of to-morrow*. London: Faber and Faber Ltd.

Kafkoula, K. 1990. *The notion of garden city in Greek town-planning in the period of 1920-1940.* Thessaloniki: Ph.D. Thesis, Technical School of Architecture of the Aristotle University of Thessaloniki.

Kalkstein, L.S. & Sheridan, S.C. 2003 *The impact of heat island reduction strategies on health-debilitating oppressive air masses in urban areas. A report to the u.s. epa heat island reduction initiative*. Available from: http://www.udel.edu/SynClim/MM5_complete.pdf [Accessed 26th March 2006].

Koppe, C. et al 2004. *Health and global environmental change; heat-waves: risks and responses. series No. 2, energy, environment and sustainable development*. Copenhagen: World Health Organization.

Lancaster R. and Slaughter D. 2000. *Garden cities worldwide; first garden city heritage museum.* Available from: http://www.hmcm.co.uk/letweb/ [Accessed 29th November 2003]

Le Corbusier. 1933. *The radiant city; elements of a doctrine to be used as the basis of our machine-age civilization.* London: Faber and Faber Limited.

More, T. 1989. *Utopia.*Edited by Logan,G.M. and Adams,R.M., Cambridge: Cambridge University Press.

Oke, T.R. 1987. *Boundary layer climates.* London: Routledge.

Papadopoulos, A.M. 2001. The influence of street canyons on the cooling loads and the performance of air conditioning systems. *Energy and Buildings* 33: 601-607.

Pignolet-Tardan, F.et al.1997. Modelling of the heat island generated by an urban unit, *Proc. intern. Building Performance Simulation Association 97* (3): 41-48.

Rosenfeld, A.H. et al 1995. Mitigation of urban heat islands: materials, utility programs, updates. *Energy and Buildings* 22: 255-265.

Santamouris, M. 2001. *Energy and climate in the urban built environment.* London: James & James.

White K.S. et al 2001. Technical Summary, Climate Change 2001: Impacts, Adaptation and Vulnerability. In: McCarthy, J.J. et al. *Climate Change 2001: Impacts, Adaptation and Vulnerability. United Nations' Intergovernmental Panel on Climate Change (IPCC)* Cambridge: Cambridge University Press.

Comprehensive water and nutrient planning for sustainable design

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ABSTRACT: The authors will look at the modern era of ecological water-nutrient planning to explicate the important lessons learned over the course of over three decades. The authors will show how these lessons learned can help to deal with the present exciting challenges and opportunities such as integrating eco-agricultural enterprise zones into urban areas, exploiting the nutrients from agriculture for the benefit of the environment, ensuring safe water supplies for the planet, and ensuring that all water-nutrient planning uses renewable energy and is carbon neutral. The opportunities for integrating these concepts into the general design process and the scale of operations for water planning projects will also be covered. Finally, some of the cascade products from water and waste treatment will be reviewed.

1 INTRODUCTION TO THE HISTORY OF WATER-NUTRIENT PLANNING

From about 7500 B.C. in the Levant (the region along the coast of the Mediterranean south of present-day Turkey and north of the Sinai), the first villages appear, with their, albeit limited, requirements for irrigation, water supply, and sanitary waste disposal. Techniques for the effective use of water and fertilizers helped to intensify crop cultivation which thus spread widely to other regions. Further toward the east, from 2500 B.C., the Sumerian and Indus Valley civilizations developed sewers for the transport of human organic waste and aqueducts for fresh water supply. Some private homes in Sumerian Moenho-Daro and Harappa, at the time, even had water flushed latrines. (Outwater 1996). With the advent of the Roman Empire, pollution and water demands had increased, and also for many other civilizations, to the point where the Romans had to build their first aqueduct in 312 B.C., because of threats to the Tiber River. (Ponting 1991). Pollution and drinking water demands have since then increased both because of per capita use and because of population increase.

From the early Middle Ages and right up to today, pollution from human/animal sanitary waste and burial grounds have presented an ever increasing challenge to the inhabitants, designers, and administrators of settlements from the village to the large city scale. During the Medieval period of Europe, sanitary waste would be either discharged into the street or waterways, or deposited into a cellar. Thus, the open spaces of many towns were filled with excrement, urine, dead animals, leftovers from food shops, and other general garbage. (Ibid.). By 1236 A.D., the Thames was so polluted that London found it necessary to build a water supply line of lead piping. (Ibid.).

The collection of sanitary waste was improved by the invention of the flush toilet in 1596 by Sir John Harrington, although this led to increased fresh water use. (Outwater 1996). Even the United States began to experience severe problems with human waste early on in its history, where the capital city of Philadelphia was shut down in 1793 for an extended period by a mass outbreak of Yellow Fever, caused by insufficient sanitary waste procedures. Only five years later, the engineer Benjamin Latrobe directed the construction of the first American city wide sewer and water supply infrastructure project. Prior to the advent of medieval metropols such as London, manure would be sent or sold to farms in the countryside, but during the eighteenth century, manure would simply be allowed to pile up in Europe. In England, horses alone produced three million tons per year. At the beginning of the twentieth century, many cities and businesses in the countryside of Europe and America began to deal with the issues of pollution and the health of fresh water supplies. By 1900, Manchester began to send its human excreta to farmers in the countryside, while the city of Halifax in England began shortly thereafter to dry, grind up, and sell its excreta also to farmers. the British architect Donkin's invention of the compost producing dry earth closet, which also separated urine from excreta, has helped to show how resource recovery may be achieved. (Ponting 1991).

Berlin up until 1927 used its wastewater, 182 million cubic meters per year, to irrigate open fields to keep the waste from rivers. However, after British engineers invented the technique to use activated sludge bacteria to process, consume, and remove organic matter, construction on plants in Germany were started already in the 1920's. Comprehensive sewage treatment of water was not achieved as a prevalent infrastructural service in the western world until the 1970's. (Lanz et al. 2006)

Despite these advances in pollution control and treatment, and the diversion of waste streams to re-use water, modern settlements are still faced with many challenges of human and animal excreta. Even today, in the United Kingdom, dogs and cats contribute 1,000 tons of excreta and three million gallons of urine every single day to the waste stream. (Ponting 1991). Further, because of population increases and higher volumes of water use, modern water supply and treatment systems are reaching their limits. Thus, three major issues out of the many others from the conventional perspective on water infrastructure, are that urine from toilets accounts for about 90% of the nitrogen and 60% of the phosphorus in wastewater, the ever increasing number and total amount of pharmaceuticals, hormones, and other biologically active substances enter the wastewater stream through this urine, and finally, the phosphorus lost in this process as a 'waste' product could be useful to make up for the predicted shortage of phosphorus useful for agriculture in the future. Many experts therefore agree that new thinking on the entire concept of waste treatment and how physical prosperity is ensured through methods of primary production is required. (Lanz et al. 2006).

2 THE MODERN ERA OF ECOLOGICAL WATER-NUTRIENT PLANNING

Early work on the subject of wastewater treatment using ecological principles was conducted at the Max Planck Institute from the 1950s, and was later taken up as a meta-scientific study by the new Environmental Protection Agency in the U.S.A. in the early 1970s. Around the same time, biologist Kathe Seidel from Germany published a paper in 1971 on the use of plants for wastewater treatment, and was later part of the team that built one of the first plant based wastewater treatment facilities in the world, in 1974 in Philadelphia. (Seidel 1971). Similar research was being conducted by Todd and McLarney during the early 1970s, with a focus on the renovation of aquatic environments and fresh water in general. (Todd et al. 1996).

With the advent of Odum's work on ecology from the early 1970s, ecological water planning became a part of the broad based field of ecological engineering. Since then, many textbooks have been devoted to this specialty, yearly conferences are held, several journals are devoted to the field, and finally, the codification of the modeling procedures of ecological systems have progressed over the last 20 years. (Ibid.). Thus, facilities built based on ecological principles can now be seen as mainstream contributions to the suite of infrastructure solutions used to meet the diverse challenges of all water-nutrient processes, from the urban to the rural scale, and from the domestic to the industrial/agricultural context. These systems meet prevalent standards of effluent quality, robustness, reliability, and are often able to react successfully to unforeseen pollutants and large shock flows just as well or better than conventional treatment systems using artificial chemicals, physical agitation, and much higher amounts of power input. There are thus several good reasons for those stakeholders who set the legislative and administrative agenda for local to trans-national environmental policy to encourage the use of ecological engineering in general and ecological water-nutrient planning for specific projects.

3 TWELVE PRINCIPLES FOR COMPREHENSIVE, ECOLOGICAL WATER-NUTRIENT PLANNING

Todd and other authors have remarked elsewhere that, based on experience, successful ecological design is based on design principles. These principles are a guide to how feedback loops, diverse species, and physical resources are most efficiently integrated into a system design that is robust, reliable, and will work based on both theory and experience. (Todd 1996).
Thus, ecology becomes one of the main cornerstones of an intellectual foundation for modern infrastructure design, so that systematic knowledge of the natural world is used to help in the formal design and continual re-design of modern treatment systems. These systems can well deal with unforeseen events, (storms, large shock flows of wastewater or surface water/rain), periodic predictable events, (the pollution from the simultaneous flushes at a football match), or simply issues that could not have been predicted by the human designers and unintended consequences, (the effects of pharmaceuticals, hormones, other personal care products in the wastewater stream, or the effects of the introduction of predator species to control certain environmental pests or pollution.) Besides Todd's work in the USA (Ibid.), Jenssen and Heistad have achieved very promising results for cold climates using light weight aggregates and wetlands for small scale systems of sewage treatment. (Jenssen et al 2005, Heistad et al 2006).

4 WHAT CAN BE ACHIEVED WITH SUSTAINABLE DESIGN?

There are various types of pollution and pollution sources that effect water. The main sources are as given in Table 1.

Table 1. Types and contents of wastewater

source	potential contents	comments
buildings for human habitation	water, various solids, bacteria, germs, parasites, organic substances, undigested food, minerals, domestic cleaning agents, toxic and harmful chemicals, pharmaceuticals, and other personal care products, up to 60,000 different chemicals (US EPA)	large and unpredictable number of types of waste, also pirate copies of approved chemicals
agriculture and aquaculture	water, pharmaceuticals, minerals, dyes, cleaning agents, pesticides, herbicides, and hormones	monitoring of recipient waters
municipal facilities	water, various solids, bacteria, germs, parasites, soaps, detergents, herbicides, pesticides, minerals, hydrocarbons, glues, organic substances, acids, CFCs, silt, humus tannins, and numerous other biochemicals	large and unpredictable number of types and amount of waste, also pirate copies of approved chemicals, weather and flooding prediction important,

	and solids	monitoring of recipient waters
industry	water, acids, salts, minerals, glues, hydrocarbons, CFCs, various solids, up to 60,000 different chemicals (US EPA)	large and unpredictable number of types of waste
energy production	Water, hydrocarbons, radioactive substances, organics, heat, minerals, acids, salts, dyes, cleaning agents, up to 60,000 different chemicals (US EPA)	monitoring of recipient waters, water usage often dependent on energy demand

There are several characteristic measurements of wastewater, including the blackwater originating from toilets, that are important to take account of in our efforts to both protect human health, the larger environment, and to exploit this source for mineral resources and as a reservoir of water for various environments. These measurement types are as given in Table 2.

Table 2. Typical measurements of chemical and biological substances in wastewater

Origin of wastewater	Type of measurement	comments
buildings for human habitation	BOD, biological oxygen demand	oxygen used to digest organics
	COD, chemical oxygen demand	oxidization of chemicals
	TN, total nitrogen	as organic N and ammonium
	TP, total phosphorus	as organic and inorganic phosphate
	TSS, total suspended solids	observable solids in water
	Coliform, number of coliform bacteria	bacteria, indicator for disease vectors
	Heavy metals, cadmium, nickel, etc.	mg/kg, small amounts are toxic
municipal facilities	BOD, biological oxygen demand	oxygen used to digest organics
	TN, total nitrogen	as organic N and ammonium
	TP, total phosphorus	as organic and inorganic phosphate
	TSS, total suspended solids	observable solids in water
	Coliform, number of coliform bacteria	bacteria, indicator for disease vectors
	Heavy metals, cadmium, nickel, etc.	mg/kg, small amounts are toxic

For example, According to the 2003 edition of the European Union Council Directive 91/271/EEC, *concerning urban waste water treatment,* biological oxygen demand, chemical oxygen demand, and total suspended solids monitoring and reductions are required in most cases, and where there are obvious and demonstrable areas of sensitive waters or coasts/estuaries, then total (Kjeldahl) Nitrogen and Phosphorus need to be monitored and reduced.

An increasing amount of wastewater production per capita, a steady rise in population, and every increasing migration to urban metropolises all contribute to greater total amounts of sewage that need to be processed in large, central facilities. Further, these facilities thus require an ever increasing amount of energy and a higher power rating to be safely equipped to handle this growing amount of sewage, and to handle possible brownouts or blackouts of power delivery. Conventional plants also seem to have difficulty dealing with unforeseen bio-active substances, heavy metals, herbicides/pesticides, and chemicals. For example, out of the estimated 60,000 chemicals on the market in the USA, according to the USEPA, less than 5,000 are registered so that it is known what their content and effects are. Finally, these plants make re-use or recycling of the water, minerals, and other potentially useful resources from sewage difficult, if not impossible.

Diversion of at least some of the raw sewage or the initially screened sewage to ecological treatment achieves a lower total amount of wastewater to be treated in central facilities, which translates often into a higher reliability of treatment, normally better treatment, and lower total energy use. Because sustainable water-nutrient facilities use nature as a guide for design, the constructions are normally very efficient in the processing of waste, use much lower power ratings, have much lower total energy demand (they often move wastewater with gravity), and are very reliable because of the complex and integrated working of the ecological systems in the design. Further, such alternative, ecological treatment facilities can become positive additions to the aesthetics of the urban or suburban area, cascade products such as fertilizer may beneficially be produced from treatment, and they can often help the public to learn about ecology, the environment, and energy efficiency.

Ecological engineering has over the years built up a record of success in dealing with these different components of municipal and domestic waste. A short review of some of these facilities shows that the ecological engineering of water-nutrient cycles has successfully dealt with many different sorts of treatment challenges:

1. municipal sewage from sources as small as single houses, Klingenberg house in Hurup, Denmark, housing developments of 60 people, at Dyssekilde, Denmark, other commercial buildings (Izembart and Le Boudec 2003), 120 person section of Providence Rhode Island municipal system (Todd et al 1996), to towns of 500,000, in Mexico (Ogden, pers. comm.)
2. municipal sewage from seasonal habitation of holiday and year round villages, at Lauwersoog, Netherlands (Izembart et al. 2003).
3. commercial kitchen wastes, including grease, at Laurepine, California, USA (Ibid.).
4. lake management to reduce organics and Phosphorus, the Meulard basin at Cublize (Ibid.).
5. treatment of minerals, hydrocarbons and trace elements from parking lots, at Oregon Museum of Science and Industry, the Hillsboro Wetlands Education Center, both in USA, and the Kolten airport, Switzerland (Ibid.).
6. multi-chemical treatment of soaps, detergents, hydrocarbons, and trace elements, from car wash wastewater, at Amagerbro car wash, Denmark (Ibid.).
7. treatment of hydrocarbons, greases, soaps, detergents, etc. as highway runoff, at highway between Bamberg and Bayreuth, Germany (Ibid.).
8. treatment of high nitrate levels from agricultural runoff to water table, based on Seidel's work, at Vierselsüchteln, Germany (Ibid.).
9. large scale experimental sewage treatment plants, treating approx. waste from 12,500 persons, at San Pasqual plant, near San Diego, USA, to test ability to produce drinking water (Ibid.).
10. sludge mineralization facility, treatment of sludge in liquid form from conventional treatment plant, at Karlebo, Denmark (Ibid.).
11. comprehensive, onsite domestic wastewater treatment, for approx. 300 people, from lavatories, toilets, and liquid kitchen waste, used for gardens, block of houses in Kolding, Denmark (Ibid.).
12. re-use of a 120 hectare (1.200.000 sq. m.) area of slag heap leftovers from mining at Germignies, France, to process wastewater and integrate the re-use of the effluent to fertilize trees for particle board production, produce compost, and contribute area to fish farming (Ibid.), secondary treatment of sewage and timber production of willows in 245 hectare facility, at Monzón, Spain (Galí-Izard).
13. ecological restoration of former 40 hectare industrial area of sawmills, factories, and pulp mills to nature preserve and wastewater treatment facility, with 15,000 visitors per year and year round population of 15,000, at Arcata, California, USA, (Izembart and Le Boudec 2003).
14. urban nature sanctuary integrated with sewage treatment plant, at the Mount View Sanitary District facility in Martinez, California (Ibid.).
15. Conventional treatment plant replacement with conventional secondary treatment and ecological polishing of wastewater to produce fertilizer for woody plant forest and as final treatment, at Cannon Beach, Oregon, USA (Ibid.).

Case studies of some of the recent projects by John Todd Ecological Design, Inc. and the designers John and Jonathan Todd can serve to illustrate more of the detail of how such beneficial results are obtained and sustained.

Providence Sewage Treatment Facility, Providence, Rhode Island, USA
Daily wastewater flows equivalent to a population of 120 persons was treated in a greenhouse, which had a common headworks with the conventional municipal system. Influent BOD was often over 250 mg/l, while because of the local jewelry industry, heavy metal constituents in the wastewater were unusually high. This facility began operation in 1989 and was functional through the 1990s, providing a proving ground for the efficient, reliable, low energy, and low cost treatment of municipal sewage. The BOD effluent was always under 10 mg/l, while other indicators such as chemical oxygen demand, total suspended solids, total nitrogen, total phosphorus, and heavy metal concentrations all showed continuous and significant reductions to within standards of treatment throughout the test period. Finally, coliform counts throughout the period showed that swimming water standards could reliably be met for the effluent.

Baima Canal, Fouzhou, China
Traditionally, raw sewage is dumped directly into Chinese urban waterways. The pilot project to cleanse canal water in Fouzhou, a city of six million in China, proved to be very successful, although it has not yet been followed up. This canal had severe problems of odors, floating solids, a visibility of only 16 cm., and a BOD of 240 mg/l. The chosen solution was a 500 meter long restorer, or weir, containing 12.000 plants of 20 different native species, with a walkway down the center for public access. The plants provide an excellent environment for specific species of bacteria and other life forms to digest the sewage, sludge, and grease, as well as remove the nitrogen. The restorer brought the BOD down to 19 mg/l, well below secondary treatment by EU standards, with a flow of 3.375.000 liters/day, or treatment for approx. 11.250 people.

Punawai Lake Restorer at Four Seasons Resort, Kona, Hawaii
A 16 million liter pond situated on the grounds of the Four Seasons Resort in Kona was required to be kept free of algae without high flushing rates in the relatively dry environment of the western side of the island of Hawaii. Two restorers harboring 26 different species of native Hawaiian fauna, fish, and shrimp, with six airlifts, and a subsurface filtration system, provide for the cleansing of the pond water. Aerobic bacteria attached to the restorer plants and gravel digest the nitrates and out-compete algae for available nutrients, making the pond clear and economically stable. Fish grown in this pond have now for years been served in the hotel restaurant. The power rating of the aeration system with the restorers went from 70 kw down to approx. 1.5kw, and finally, the facility has recently won an environmental award from the USEPA.

Tyson Poultry facility, Berlin, Maryland, USA
The original wastewater treatment facility for the processing of chicken waste was fined by the USEPA, and Tyson therefore sought alternative treatment methods for this facility. John and Jonathan Todd designed a treatment system using 12 weirs, 42 meters long, containing 25 species of native plants as a platform for beneficial bacteria. Results obtained by the USEPA showed that the facility treating 4.500.000 liters/day of chicken waste at 418 mg/l BOD during the summer, achieved a 20% reduction in sludge production, which translated into a cost savings per year of 55.000 dollars, a mean actual effluent BOD of 12 mg/l, and energy savings of approx. 3.500 kwh/day, or a cost savings from this energy demand reduction of over $70.000/year.

M&M Mars Candy Factory, Waco, Texas, USA
High sludge disposal fees and the environmental risks associated with off-site disposal led the M&M Mars Company to install a John Todd designed vertical flow reed bed wastewater treat-

ment facility. Such designs utilize common marsh reeds, such as *phragmites communis* to oxygenate the water column and to be the platform for beneficial aerobic and anaerobic bacteria, which thereby breakdown solids to mineral components. This facility has been able to reduce the volume of the sludge by 98%, pathogens are destroyed, and organics are broken down and mineralized, resulting in the continual production of stabilized sludge that can be stored in windrows for future land application. The 360 sq. meter reed bed treats over 83.000 liters of bio-solids/month. The $50.000 reed bed was thus able to eliminate the annual $31.500 cost of the disposal of the sludge.

Peace & Plenty Beach Inn hotel, Great Exuma, Bahamas
The 16 room inn on the island of Great Exuma originally discharged primary treated sewage from a septic tank into a deep injection well. This is certainly not ideal as the Bahamas and the region is characterized by Karst geological formations and by ooligotrophic coral reefs, or hyper sensitive to nutrient overload. The hotel produces a total load of approx 13.500 liters/day of sewage. A subsurface flow constructed wetland was chosen to produce water suitable for the irrigation of the hotel landscaping, or to deposit down the injection well. Such facilities are highly reliable producers of reduced sludge amounts, reduced BOD to normally below 10 mg/l, and in this case, with a re-circulating filter and a sand filter, reduced COD, and reduced nitrates and phosphorus. Laboratory results from this facility are expected shortly.

CONCLUSION

Right from the Middle Ages and until today, there continue to be serious challenges to the ability of human societies to adequately deal with sewage originating from the human or animal digestive systems. Even as our technical ability at cleansing and disinfecting water has increased, per capita water usage has increased, world populations have increased, and people have now concentrated themselves into ever greater megalopolises, i.e., Mexico City at 16 million, thus exerting ever greater challenges to successfully treat water to a reasonable standard to protect health and the natural environment. A staggering three billion people in the world do not have proper sewage treatment, so that one and a half billion people all over the world suffer, at any one time, from parasitic worm infections due to human excreta and solid wastes in their near environment. (EAWAG 2000a, EAWAG 2000b).

Because of this situation, since the 1950s, a growing chorus of scientists, engineers, designers and other stakeholders have spoken up for new thinking when it comes to the issue of wastewater treatment, and the new field of ecological engineering has since provided many new and reliable innovations for treatment using the principles of ecology and the vast knowledge and physical resources of planetary life. Thus, the ecological viewpoint in engineering design must now be seen as a mainstream contribution to infrastructure design for human settlements. (EAWAG 2000b).

The numerous examples of the continued successful use of ecological engineering for sustainable design of infrastructure shows that competent and relatively knowledgeable designers can be expected to solve many formerly intractable issues of how to treat large amounts of sewage, industrial waste, or agricultural waste, while at the same time producing different types of beneficial cascade products, such as woody plants, minerals, compost, fertilizer, cash crops, and water for various purposes, such as fish farming or environmental restoration.

REFERENCES

EAWAG/SANDEC. 2000a. WSSCC Fifth Global Forum MAP Executive Summary Working Group on Environmental Sanitation. http://www.eawag.ch/organisation/abteilungen/sandec.index_EN

EAWAG/SANDEC. 2000b. *Bellagio statement Clean, healthy and productive living: A new approach to environmental sanitation.* http://www.eawag.ch/organisation/abteilungen/sandec.index_EN

Galí-Izard, T. 2005. *The same landscapes Ideas and interpreta*tions. Barcelona, Spain: Editorial Gustavo Gili SA.

Heistad, A. & Paruch, A. & Vråle, L. & Kinga, Á. & Jenssen, P. 2006. A high-performance compact filter system treating domestic wastewater. *Journal of Ecological Engineering.* 2006.

Izembart, H. & Le Boudec, B. 2003. *Waterscapes Using plant systems to treat wastewater.* Barcelona, Spain: Editorial Gustavo Gili SA.

Jenssen, P. & Mæhlum, T. & Krogstad, T. & Vråle, L. 2005. High performance constructed wetlands for cold climates. *Journal of Environmental Science Health A*. 40 (6-7), 1343-1353.

Lanz, K. & Müller, L. & Rentsch, C. & Schwarzenbach, R. 2006. *Who owns the water?* Baden, Switzerland: Lars Müller Publishers.

Ogden, Michael. 2006. Personal communication.

Outwater, A. 1996. *Water A natural history.* New York, N.Y.: Basic Books.

Ponting, C. 1991. *A green history of the world The environment and the collapse of great civilizations.* New York, N.Y.: Penguin Books.

Seidel, K. 1971. Macrophytes as functional elements in the environment of man. *Hidroliologia* 12, 121-130.

Todd, J. & Josephson, B. 1996. The design of living technologies for waste treatment. *Ecological Engineering* 6 (1996) 109-136.

Van der Ryn, Sim. 1995. *The toilet papers Recycling waste and conserving water.* Sausolito, CA.: Ecological Design Press.

Noise abatement from the point of view sustainable environment

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ABSTRACT: Since it has been discovered that quality is more important than quantity of built environment, noise abatement is one of the issues of sustainable environment studies. Because, one of the criteria for obtaining indoor and outdoor environments of good quality is prevention of noise pollution. Although noise has bad effects on human health, it is most ignored one among the other pollution effects. The effects of noise pollution are not as striking as the others; they are cumulative and/or indirect, so, these features cause insufficiencies in noise abatement works. Due to bad planning and fast growth of cities, noise exposure is also higher in developing countries. Such a condition makes the building components' resistance very important against unwanted sound transmission. The aim of this paper is defining the design criteria for getting acoustically healthy environment from urban scale to the materials used in buildings.

1 INTRODUCTION

Sustainable design and acoustics have fundamental concerns for environmental impact, profitability and health and safety, at the starting point. Having acoustical comfort is very important for nearly all kind of environment we live in, in that, poor acoustic conditions can cause dangerous, unhealthy environments while good acoustics can increase the overall comfort level of a space. Increasing level of noise pollution is one of the most important issues of acoustics, since it ruins the acoustical quality of environment. Addition to this, noise control is one of the most important issues of sustainable development of environment as well as the sustainable construction design.

2 EFFECTS OF NOISE

Although living in a complete silence seems impossible for human beings, today's increasing noise levels affect our lives seriously. Because increasing noise levels prevent us to live in a healthy environment. But, to understand the effects of it, it can be useful to look at what the noise is.

2.1 *Definition of noise*

There is a difficulty for defining what the noise is, since, physically, there is no distinction between sound and noise. Sound is a subjective and the complex pattern of sound waves is labelled noise, music, speech etc. So, noise can be defined as unwanted sound.

According to World Health Organization (WHO), Community noise (also called environmental noise, residential noise or domestic noise) is defined as noise emitted from all sources except noise at the industrial workplace. Main sources of community noise include road, rail and air traffic, industries, construction and public work, and the neighbourhood (WHO, 1999). One or more of these noise sources affects most of people during day or night time.

Also according to WHO Constitution the definition of 'health' is given as: "A state of complete physical, mental and social well being and not merely the absence of disease or infirmity". This broad definition of health embraces the concept of well-being and, thereby, renders noise impacts such as population annoyance, interference with communication, and impaired task performance as 'health' issues.

2.2 *Bad effects of noise on human health*

Although noise has bad effects on human health, it is most ignored one among the other pollution effects. The effects of noise pollution are not as striking as the others; they are cumulative and/or indirect, so, these features cause insufficiencies in noise abatement works.

The perception of sounds in day-to-day life is of major importance for human well-being. Communication through speech, sounds from playing children, music, natural sounds in parklands, parks and gardens are all examples of sounds essential for satisfaction in every day life. According to the International Programme on Chemical Safety (WHO 1994), an adverse effect of noise is defined as a change in the morphology and physiology of an organism that results in impairment of functional capacity, or an impairment of capacity to compensate for additional stress, or increases the susceptibility of an organism to the harmful effects of other environmental influences. This definition includes any temporary or long-term lowering of the physical, psychological or social functioning of humans or human organs. The potential health effects of community noise include hearing impairment; startle and defense reactions; aural pain; ear discomfort speech interference; sleep disturbance; cardiovascular effects; performance reduction; and annoyance responses. These health effects, in turn, can lead to social handicap; reduced productivity; decreased performance in learning; absenteeism in the workplace and school; increased drug use; and accidents. In addition to health effects of community noise, other impacts are important such as loss of property value (WHO, 1999).

3 NOISE ABATEMENT STRATEGIES

In 1999, WHO published guidelines for the community noise to prevent people from the bad effects of noise pollution. In WHO report, noise is defined as both a local and a global problem. Governments in every country have a responsibility to set up policies and legislation for controlling community noise. So, in recent years many European countries has changed or updated their guidelines or standards about the noise as well as the sound insulation criteria. Also, it is suggested that, there is a direct relationship between the level of development in a country and the degree of noise pollution impacting its people. As a society develops, it increases its level of urbanization and industrialization, and the extent of its transportation system. Each of these developments brings an increase in noise load. Without appropriate intervention the noise impact on communities will escalate. If governments implement only weak noise policies and regulations, they will not be able to prevent a continuous increase in noise pollution and associated adverse health effects. Failure to enforce strong regulations is ineffective in combating noise as well.

To minimize noise levels, action should be taken where possible to reduce noise at the source. When we think about urban scale, firstly, sources of community noise must be decreased as much as possible. Then, land-use planning should be guided by an environmental health impact assessment that considers noise as well as other pollutants. Finally, building constructions must be taken into consideration against the noise, which is both coming from the outside and coming from the neighbours.

Another important steps of noise management are defined as to develop criteria for the maximum safe noise exposure levels, and to promote noise assessment and control as part of environmental health programmes.

4 SUSTAINABILITY AND NOISE CONTROL

Since, an architect is supposed to design an ideal environment for whatever man chooses to do, most of the time, building design have most important role against noise between the source and receiver. Also, it is very important for the architect to reduce the problem of noise control by site planning as well as internal planning and construction design. If the site selection, planning and also material/ construction selection is made by considering the noise control at the beginning of the design, the result can be more effective. And also this kind of approach can be effective for reducing the use of construction material, time, and also workmanship in addition to reduction of the cost. So, it can become a sustainable design approach at the same time. Here, also we can have a short look of the definition of the sustainability and noise abatement works within it.

4.1 *The terms sustainability and sustainable construction*

"Future generation is the most important". *Confucius*

Since it is discovered that World has limited sources that human beings need, sustainability is (must be) one of the most important criteria of life. World Commission on Environment and Development defines sustainable development as, development, which meets the needs of the present without compromising the ability of future generation to meet their own, needs (Asdrubali, 2006).

We can define sustainability in three-dimensional concept as environmental, social and economic sustainability. Human well-being is the main objective of these aspects, since it is at the intersection of them.

Urban development and built environment are very important factors of sustainability, as they cause many damages or changes in the environment. This fact is also described by many authorities or references. One of these definitions is below, from Sustainable Architecture and Building Design (SABD) web site;

"*Architecture presents a unique challenge in the field of sustainability. Construction projects typically consume large amounts of materials, produce tons of waste, and often involve weighing the preservation of buildings that have historical significance against the desire for the development of newer, more modern designs*".

Sustainable building involves considering the entire life cycle of buildings, taking environmental quality, functional quality and future values into account. In the past, attention has been primarily focused on the size of the building stock in many countries. Quality issues have hardly played a significant role. However, in strict quantity terms, the building and housing market is now saturated in most countries, and the demand for quality is growing in importance. Accordingly, policies that contribute to the sustainability of building practices should be implemented, with recognition of the importance of existing market conditions. Both the environmental initiatives of the construction sector and the demands of users are key factors in the market. Governments will be able to give a considerable impulse to sustainable buildings by encouraging these developments. The OECD project has identified five objectives for sustainable buildings:

- Resource Efficiency
- Energy Efficiency (including Greenhouse Gas Emissions Reduction)
- Pollution Prevention (including Indoor Air Quality and Noise Abatement)
- Harmonization with Environment (including Environmental Assessment)
- Integrated and Systemic Approaches (including Environmental Management System) (SABD- http://www.arch.hku.hk/research/BEER/sustain.htm)

As it is seen in the objectives above, Noise abatement is one of the issues of sustainable building design as well as the sustainable environment. And also it can be seen that sustainable design means much more than using recycled materials.

4.2 *Steps for having acoustical comfort in built environment considering sustainability*

Health & Safety can be considered at the first rows of sustainable design. As it is explained before, hearing impairment that is caused by high noise is one of the leading occupational hazards. Other health problems associated with noise exposure have also been explained in previous sections.

Comfort - "Few people have ever experienced real comfort - thermal, visual, or acoustic - but once they do, they tend to want more of it." (Hawken, Lovin & Lovins. Natural Capitalism) Occupants in a noisy space can feel irritable, distracted, anxious, hostile and annoyed, sometimes without consciously making the connection to noise (Acoustics.com).

Human efficiency is also very important for sustainable design. Since employees are usually a company's most valuable resource, creating a space in which they can maximize their productivity is key. Many studies over the last 12 years convincingly document that noise is the number one (by far) impediment to workplace productivity (Acoustics.com).

Functionality/Building Longevity is another criteria for sustainable design. A building is, primarily, a controlled environment, which facilitates human activity and, as such, influences human conduct and attitudes. The awe-inspiring hush of a cathedral, the quiet of a library, the brilliance of a concert hall need not to be the results of fortuitous accidents (Yerges, 1969). For example, speech intelligibility is important for designing a classroom, courtroom, etc., speech privacy is important for open office, call centers, etc., music is important for a performance space, concert hall, recording studio, etc., a quiet atmosphere is important for a library, museum, healthcare facility, etc. and so on. Acoustics that meets the needs of function is also very important for sustainability of the building as well as its longevity.

How the Building Impacts the Environment – according to sustainability criteria, the operation of the facility should not harm (pollute) the environment. Although the LEED program takes into account water, air, land and light pollution, it surprisingly does not include noise pollution. Although controlling/limiting light pollution is very important, noise pollution can be far more annoying and harmful. Additionally, noise is much more difficult to limit. (Acoustics.com).

Use of Recycled (Sustainable) Materials is one of the solutions for sustainable design. Sometimes it is not possible to control noise or solve the acoustical problems without using acoustical materials. In such a situation, sustainable/ recycled acoustical materials must be preferred, since there are many recycled/sustainable acoustic products that work as well as (or better than) non-recycled acoustic products.

5 DESIGNING FOR NOISE CONTROL

Basically, sound originates with a source, travels via path, and reaches a receiver. Like this, noise occurs different sources of city and reaches us (or spaces, where we live) by decreasing or increasing effect of environment (path). This fact makes important to consider studies for reducing the noise at the source. This can be obtained by designing and choosing less noisy machine/ equipment and more sensitive installation of them, regular service of maintenance & repairing as well as active control systems. Also there are some emission standards that aim to reduce noise level of different kind of sources (machines, equipment, vehicles…etc.).

Also, it is possible to make some studies on user (receiver) to prevent him bad effects of noise. These precautions can be listed as, education of the user/ occupant, reduction of the noise exposure time, personal protection against noise, and using masking effect of noise.

But in our life, most of the time we are affected by high noise level of cities even though we are not aware of it, so, controlling the noise at built environment (path) has the main role of noise abatement works. Control of noise at built environment starts with the city planning. Then scale gets smaller, building area design, building design, interior design of the building, building component design, material selection are other important steps of the noise control. As it is mentioned before, if the site selection, planning and also material/ construction selection is made by considering the noise control at the beginning of the design, the result will be more effective. But, on the other hand, usually due to bad planning and fast growth of cities, noise exposure is also higher in developing countries. Such a condition makes the building components' resistance very important against unwanted sound transmission.

5.1 *City planning*

It is evident that noise is a major consideration, not only in the planning and construction of individual buildings, but also in the wider context of town and regional planning (Moore, 1988).

With careful planning, noise exposure can be avoided or reduced. Also according to the noise management strategies of World Health Organization, land use planning is one of the main tools for noise control and includes:

a. Calculation methods for predicting the noise impact caused by road traffic, railways, airports, industries and others.

b. Noise level limits for various zones and building types. The limits should be based on annoyance responses to noise.

c. Noise maps or noise inventories that show the existing noise situation. The construction of noise-sensitive buildings in noisy areas, or the construction of noisy buildings in quiet areas may thus be avoided. Different zones, such as quiet areas, hospitals, residential areas, commercial and industrial districts, can be characterized by the maximum equivalent sound pressure levels permissible in the zones. More emphasis needs to be given to the design or retrofit of urban centers, with noise management as a priority (e.g. "soundscapes") (WHO, 1999).

5.2 *Reduction of external noise by screening*

If a screen element (usually it is a wall, but sometimes planting can be used for the same purpose) is set between a source of sound and a listening position, the level of sound heard will depend on the amount of sound energy diffracted over the top edge (Moore, 1988).

Use of noise barriers as screening element is quite often for controlling noise within the sound transmission path. They are usually installed for protecting dwellings close to the traffic source. Noise barriers performances are usually evaluated in terms of transmission loss and diffraction phenomena; noise absorption performances are also important in order to reduce reflection phenomena. (Cotana et.al, 2005)

Noise barriers are solid obstructions built between the highway and the homes along the highway. Effective noise barriers can reduce noise levels by 10 to 15 decibels, cutting the loudness of traffic noise in half. Barriers can be formed from earth mounds along the road (usually called earth berms) or from high, vertical walls. Earth berms have a natural appearance and are usually attractive. However, an earth berm can require quite a lot of land if it is very high. Walls take less space. They are usually limited to 25 feet in height for structural and aesthetic reasons. Noise walls can be built of wood, stucco, concrete, masonry, metal, and other materials. Many attempts are being made to construct noise barriers that are visually pleasing and that blend in with their surroundings (FHWA- U.S. Department Of Transportation Federal Highway Administration).

However, barriers do have1imitations. For a noise barrier to work, it must be high enough and long enough to block the view of a road. Noise barriers do very little good for homes on a hillside overlooking a road or for buildings which rise above the barrier. Openings in noise walls for driveway connections or intersecting streets destroy the effectiveness of barriers. In some areas, homes are scattered too far apart to permit noise barriers to be built at a reasonable cost (FHWA).

Vegetation, if high enough, wide enough, and dense enough (cannot be seen through), can decrease highway traffic noise. A 200-foot width of dense vegetation can reduce noise by 10 decibels, which cuts the loudness of traffic noise in half. It is often impractical to plant enough vegetation along a road to achieve such reductions; however, if dense vegetation already exists, it could be saved. If it does not exist, roadside vegetation can be planted to create psychological relief, if not an actual lessening of traffic noise levels (FHWA).

5.3 *Building design*

5.3.1 *Definition and the analysis of the noise problem*

The control of noise starts with the choice of site and the importance of noise as a factor in that choice depends on the purpose of the building. For example, residential buildings are much more sensitive against the noise than shopping centres or office buildings. It is then necessary to find out the sources and levels of noise to be expected on the selected site. It may be produced by different sources due to human activities: transport systems, industrial and trading plants, yards and recreative activities. Some common external noise sources can be listed as, aircraft, road traffic, rail traffic, factories and car parks.

Noise sources within a building are so multifarious that, it seems impossible to enumerate. They may be broadly ascribed to the activities of occupants and the operation of machines and equipment. In all cases, the distinction between the air-borne and structure-borne noise should be taken into consideration (Moore,1988).

5.3.2 *Site and location of building*

Choosing a site consistent with the function of the building is a good way of starting, if it is possible. A rest home must not be next to the railroad, or a concert hall must not be adjacent to a bus station. On the other hand, sometimes a critical building is needed to be located on a difficult site. There are of course solutions for acoustical problems in such a situation, but they are complex and expensive. It is probably possible to solve any acoustical problems but choosing another site instead of complex solutions may be wiser way and more appropriate for sustainability at the same time (Yerges, 1969).

Location of building is also important. Whenever possible, the building must be located as far from the noise sources as possible. If there is noise source from one direction, it can be useful to arrange orientation of the building according to this data.

5.3.3 *Layout and design of spaces*

It is possible to reduce noise by appropriate planning of the interior spaces within the building. To be able to make this arrangement at the design stage, spaces can be divided into three categories according to their sensitiveness against noise. These are quiet, noisy and buffer spaces. It is a common principle to group quiet spaces one area, noisy spaces another, and buffer spaces between them. Corridors, storerooms, closets and similar spaces can be evaluated as buffer zones between noisy and quiet spaces. Also, it is a good solution to put the quiet spaces as far as possible from external noise sources. While designing the building it must be always in mind that reduction of noise by planning is a three dimensional matter.

5.3.4 *Choosing the exterior construction*

After making the design, materials and constructions must be selected carefully for the exterior envelope of the building. The exterior includes, roof, fenestration, louvers, and all significant details as well as the exterior walls.

There is a point that should be emphasized, if high noise levels in cities are noticed, building components' resistance to sound transmission is getting more important. So, the quality of components of exterior envelope must be increased to obtain better sound insulation values.

On the other hand, material and component selection must be done by considering the sustainability criteria. When considering the sound transmission resistance of a building component, by increasing the mass property, it is possible to increase sound insulation value of it. But, this solution may not be useful in every situation. Instead of doubling the weight of the wall to obtain necessary sound insulation value, adding some recycled or natural insulation layer can be more effective and sustainable way, since there are many natural and recycled acoustical materials are developed.

5.3.5 *Choosing the interior construction*

While considering about the interior construction first step is to choose the materials, components or constructions that can serve as barriers to prevent transmission of any kind of internal noise. Second decision is about the finishing materials of the space. It involves sound absorption or reflection ability of the materials. But like exterior elements/components of building, interior materials or components must be selected by considering sustainability as one of the major criteria.

For example, in a common internal heavyweight partition wall with an interposed insulating layer, concrete or bricks masonry, are responsible for most of the potential "damage". They imply high-energy demand for production process and for transport, mainly influencing human health damage category by respiratory diseases due to inorganic fuel combustion air emissions. The fixation system of the insulation layer supply higher eco-impacts than the particular insulation material. In case of gluing by polyurethane adhesive, the main impact is given by carcinogens and respiratory diseases from inorganic substances. Mechanical assembly, typical of lightweight partition solutions, is then preferable. (Desarnoulds et.al, 2005).

5.3.6 *Developments on sustainable materials for noise control*

Since it is very important to selection of sustainable materials for noise control, research and development studies are stimulated on new materials as alternatives to the traditional ones. These materials can be divided into two main categories as natural materials (cotton, hemp, sheep wool, flax, clay, etc.) and recycled materials (rubber, plastic, cellulose, carpet, etc.) These materials are in many cases comparable to traditional ones as far as thermal and acoustic performances. Though for many products physical properties have not been deeply analysed and are not yet certified, they have already reached a technical and commercial maturity; in Italy, for example, many sustainable materials are listed in official prices lists for public tenders (Asdrubali, 2006).

Also studies show that, for heavy and lightweight double-leaf partition, various alternative sound insulating layers (sheep wool, latex-coco, flax, cellulose, wood wool) are equal or better than mineral wool with the same thickness. For these animal or vegetal materials, it is however difficult to time durability without specific processing. Cork is not very effective regarding the usual airborne sound insulation purposes. For impact sound insulation, natural and recycled materials (cork, rubber, wood wool, coconut fibers, cardboard, etc.), correctly designed and used (directly as floor finish or under a floating floor or surface), are generally as good as other traditional products. These “sustainable” materials can also be used in room acoustics, even if their absorption coefficient is generally lower than mineral wool (Desarnoulds et.al, 2005).

The production of these materials generally has a lower environmental impact then conventional ones, though a proper analysis of their sustainability, through Life Cycle Assessment procedures, has to be carried out. Also the total energy demand has to be accurately evaluated, since not always an ecological material requires less energy in its life cycle than a traditional one. Furthermore, many of these materials are currently available on the market at absolutely competitive prices. There is however a need to complete their characterization, both from an experimental and a theoretical point of view, and especially to propose a standard and unique procedure to evaluate their sustainability (Asdrubali, 2006).

6 CONCLUSIONS

Noise control is one of the most important issues of sustainable building design, since it affects the human well-being directly. On the other hand, controlling the noise level within the acceptable limits is one of the most important criteria for a sustainable environment. For this reason, the importance of the acoustical comfort in terms of sustainability must be emphasized in LCA, LCC studies as well as in the sustainable building design.

REFERENCES

Asdrubali, F. 2006. Survey On The Acoustical Properties Of New Sustainable Materials For Noise Control. *Euronoise 2006.* 30 May-1 June 2006, Tampere, Finland.

Cotana, F., Rossi, F., Filipponi, M. 2005. Performances Of Resonant Barriers For Transport Noise Abatement. *Twelfth International Congress on Sound and Vibration*. 11-14 July 2005. Lisbon, Portugal.

Desarnaulds,V., Costanzo, E., Carvalho,A., Arlaud, B.2005. Sustainability Of Acoustic Materials And Acoustic Characterization Of Sustainable Materials. *Twelfth International Congress on Sound and Vibration*. 11-14 July 2005. Lisbon, Portugal.

Moore,J.E., 1988. Design for Good Acoustics and Noise Control. Macmillan Education Ltd. Hong Kong. p.56-100.

World Health Organization (WHO). 1999. Berglund, B., Lindvall, T., Schwela D.H. (editors). Guidelines For Community Noise. London.

Yerges, L., 1969. Sound, Noise and Vibration Control. Van Nostrand Reinhold Co. New York. p.17-30

Sustainable Architecture and Building Design. http://www.arch.hku.hk/research/BEER/sustain.htm.

Acoustics.com: Article-What Does Sustainable Design Sound Like? http://www.acoustics.com/ra_sustainable.asp.

U.S. Department Of Transportation Federal Highway Administration (FHWA)- Highway Traffic Noise http://www.fhwa.dot.gov/environment/htnoise.htm.

Regenerating lost places in old cities (link linguistic with sustainability)

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ABSTRACT: Karim Khan Street is a main axis in Shiraz, which has evolved throughout history. Its development started during Zand era, but has experienced both Pahlavi I and II eras as well. Each section of the street is reflecting the design principles of the corresponding era to such as a sentence in Chomsky's semantic meaning. However, due to the passage of time and dilapidation and or demolition and replacement of some of the original buildings, the sentences are disrupted and the transfer of meaning is interrupted now. The article has suggestions for reconstructions of meaning for current users, through certain physical interventions, and reconstructions.

1 FOREWORD:

Each of Chinese, English and Spanish languages makes use of its particular grammar and vocabulary. Being unable to hear, people gesticulate to speak to each other. Sailors use flags to communicate and even dogs bark to imply a meaning. Likewise when classifying architecture as a language, the first questions to be answered would be questions such as "what is told?" and "who are the addressees?"

Here are some definitions given in dictionaries:

Language: Words and methods they are used

Architecture: The art or science to construct buildings

In regard of messages which architects represent to each other by a design, more concentration and attention is required, but all the people are not deemed to be interested in finding out these messages. There is another issue which people are more concerned about, and that's the environmental aspects of a design. Buildings are speaking not only to architects and people but also to the environment …

If there is a harmonization to be made between architecture and environment, new approaches shall be developed to facilitate the communication. The buildings of the city shall be more urban. "Individualism" could be a title for the art of urbanizing the buildings. The so called "architecture language" theory of *Jenks*, is an approach to harmonization and coordination. The buildings can speak and they are even able to listen.

The environment speaks also; it speaks using a variety of languages and sounds…

Since architecture is an everywhere-exposed art, the language used by architects and urban planners shall be easily interpretable to the local language. And this is where it's understood that the environment has got various messages to represent.

Admirable buildings and other urban places shall speak to the whole environment: other buildings, animals, plants, people and any other phenomenon.

2 STREET; THE FORGOTTEN URBAN SPACE:

Urban space by its very meaning is the environment which is defined by the daily activities and events taking place in it. Street is one of the most significant urban spaces nowadays being subject of special attention and consideration.

"Streets are not only conduits for the physical movement in our daily lives, but they also have the potential to be the conduits for community cooperation, organized public action, and civic pride. Streets must be regarded as a vital public resource. Street improvement projects should not only increase traffic efficiency, but fulfill other objectives as well. It is especially important to seize the opportunities of street improvement conditions, reinforce community identity, provide for a variety of pedestrian activities, and revitalize community business". (Owen 1987)

Looking at a traditional street, evolution of events and changes could be found in various physical and spatial aspects in every era, but the major issues to give a special character to the street environment, are three physical aspects dedicating a particular meaning to the street each and every. These three are: special dimension, special arrangement and special position. (Anderson 2001)

Any physical component of the city has got a form, and coordination between these components will create the special formation and construction of a city. Thus any physical component of the city could be planned and so could the compound of these components, to generate streets, plazas, urban texture, monuments and the skyline. Although the form and construction of the traditional city could have been developed in a sluggish, gradual process and devoid of an official plan; this development has been in accordance with the acceptable and known models of development.

Nowadays several non-local leverages influence the formation of a city. These models and regulations shall be defined as frameworks of planning and development which must be based on the particular history, culture, location and topography of the city so that the character of the city is retained.

3 EXPERIMENTING THE SPACES AND THE ROLE OF THE EXPERIMENTER:

City is a discourse, and this discourse as the matter of fact is the language by which the city talks to its residents. We are talking to the cities we live in, just by looking at them, walking in them and totally living in them.

Whereas the urban spaces could have a fundamental effect on the public viewpoint and the social and functional specification of an axis, and since these spaces are experienced and felt during trips; the role of experimenter and the way he/she surveys the environment is the key point, because a good city is the one in which people discover their origins. Time is one of the implicit dimensions which are brought to consideration by the environment. Historical environments have more capability in respect of reminding the issue of time. Having a remarkable historical background, the *ZAND* axis in Shiraz benefits from such capability. But overlooking the abilities of this environment in respect of its time-reminding role has caused some illegibility within the urban space. These troubles shall be detected, missed chains shall be identified, and after review and assessment of all issues, a constructive step shall be taken in order to revive these places as the sense of belonging to a place is born only when the environment guides the people.

In reviewing the creation of a sustainable urban planning, the tools used for this thing, represent criteria for definition of public places. These are the criteria: safeness, accessibility, legibility, attractiveness, comfort, and livability. Hierarchy of the mentioned criteria is directly connected to the needs and wishes of citizens and local communities in relation to sustainable open spaces. The main insistence is on active participation of citizens in bringing the urban plans. The participation of citizens is considered one of the main instruments in attaining tenable development, as well as in identification, preservation, creation and realization of new local qualities.

One of the approaches to achieve such a target is to study the structure of the urban language within the related urban space by means of linguistic theories and the ways constructivists use this reconnaissance approach.

4 LINGUISTIC AND URBAN LANGUAGE OF PEOPLE IN SHIRAZ CITY:

A common language in a city is a comprehensive structure which is much more complex than the individual languages. This language is not a concise grid but the grid and structure with their very function. It's a complex of varying languages which people create when they are engaged with their man-building activities. (Alexander 1977)

And by presence of such structure, we will have a live language in the city, exactly like the way our common oral language is alive. All the people speaking English are using this language in common whilst each of them has created a language in mind which is personal to some extent. This is why we are able to recognize his/her favorite words and method of speaking and the delicate manner in which he/she speaks. It's to be noticed that we obviously have so many things in common while we are using our personal languages, and such things are the ones that communize our language.

Perceiving spaces in Shiraz by its experimenters is related to their common points of view, because the manner of interaction with the environment is derived from the general culture of a society and this caused by their common linguistic points.

It's to be noticed that the studying of this environment as an urban context and the historical perceive of that is the major concern here. In other words the distinguishable issue and the common point (in regard of time) for the experimenters of the environment (Shiraz residents), is the physical environment. Thus they perceive by means of time and identifying the related environment. This is where *Noam Chomsky* – a generative linguist – proposes the theory which considers the language as a subjective issue.

Chomsky divides the language into two branches: surface structures and deep structure. Deep structures as they are defined in the transformative-generative theory are subjective and actual structures. These deep structures together with the transformative rules by which they are related to surface structures, vocal utterances and meanings; constitute the rules on which a language learned person is dominated. According to *Chomsky's* approach, a language's grammar could be studied on the basis of three structures: syntactic structure, meaning structure and vocal structure.

In addition to the outer layer of language called surface structure, *Chomsky's* theory brings forward the under layer he called deep structure. Deep structures are conceptual beings on which the surface structure (the objective feature of the language) is based. The transformation between the deep structure and the surface structure is performed using "transformative grammar". (Chomsky1975)

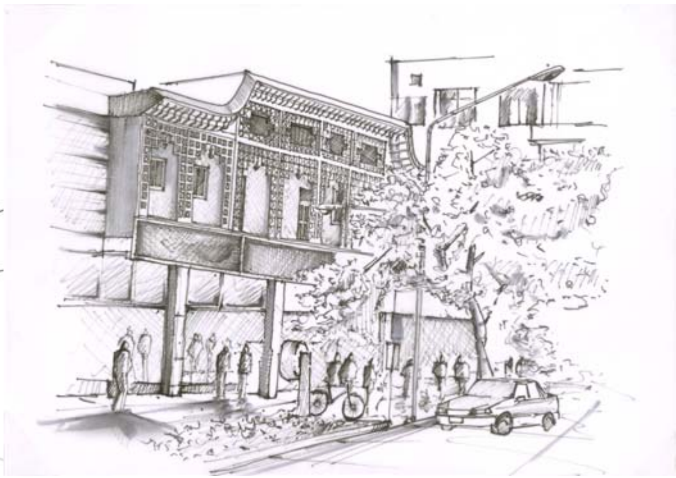
Application of *Chomsky's* theories and more generally application of linguistic approaches by people to analyze architecture and urban planning; has caused many models to be developed in order to determine the deep structure and the way it transforms to surface structure.

Therefore these deep structures represent numerous abilities of the users of a language. Since the users themselves feature the way the deep structures are used and in other words the diversity of application of these deep structures caused them to be called "generative grammar". According to *Chomsky's* linguistic point of view, there are some deep structures within the urban space which could lead to surface structures using some principles and rules. Whereas these deep structures differ in various points of view, in this research they are defined as follows: the ability of people to perceive the physical environment's factors in the framework of time and also to perceive the parameters of recognition and the reconnaissance of the interaction between the space and users under proper conditions.

5 KARIMKHAN-E-ZAND AXIS IN SHIRAZ; AN EXPOSITION OF HISTORY IN THE MIDDLE OF URBAN TEXTURE:

The city of Shiraz with an ancient background and unique history, and having a structure formed within *AL-E-BOOYA* and its precedent eras has been the subject of different incidents each of which forming different urban developments in various physical aspects of the city. One of the most dominant fields of urban development is the one along *KARIMKHAN-E-ZAND* axis, being singly able to tell the historic story of Shiraz urban development. Being one of the important link routes, the *ZANDIE* Street has got an old background in Shiraz urban formation process.

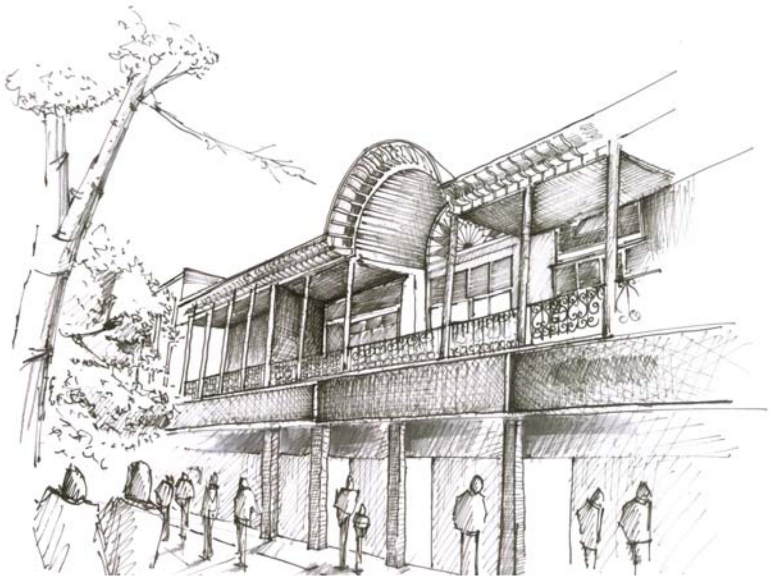
‘Figure 1, An example of Qajar’s era building in Zand Street



‘Figure 2, An example of Pahlavi I’s era building in Zand Street

Following the prosperity of urban planning within the *SAFAVIE* era, a new axis was formed similar to its predecessors and preserving the main structural elements of the city. The current *ZAND* axis is a part of the mentioned axis, which was extended from the governmental garden to the king's garden and both sides of the axis, was also gardened by patricians. According to the found images related to Shiraz in *SAFAVID* era, it’s likely that the current *ZAND* axis has had a role similar to *CHAHRBAGH* (Quadra-garden) street of Isfahan. Presently the remained parts of *SAFAVID* gardens along the *ZANDIE* Street are not hard to find.

Within the *ZANDIE* era there were governmental facilities built along the axis approaching the king's garden, and this led to further significance of the axis within the general structure of the city. During the *QAJARIE* era, the water from SHESHPIR spa was channeled to Shiraz and the axis was transformed into a Quadra-garden format having the mentioned water passing among. The two sides of the route housed the patricians' and the government officials' gardens. Nowadays the axis is still called "Quadra-route" among the elderly citizens of Shiraz. Following the kingdom of *REZASHAH PAHLAVI*, and the promotion of western culture, there were streets built for the transportation of automotives and consequently the Quadra-garden format was ruined and the axis changed into a vacant street. Currently the *ZAND* street is flowered as its common in similar boulevards, but regarding the open spaces in the streets body and the proper proportions of width and body; it still has retained much environmental values and deserves reconsideration.



‘Figure 3, An example of Qajar’s building’

The *KARIMKHAN-E-ZAND* axis in Shiraz is one of the main streets of the city and plays a multifunctional role in the city by its structural presence and also by hosting a concentration of various urban and touristy activities. One remarkable issue in respect of this axis is the linking role of it: it’s the axis by which the ancient texture of the city is linked to the central texture on one side and to the modern texture of the city on the other.

The major concern of this article is the lack of expression regarding the three historic eras along the axis and the importance of such expression. It's obvious that this axis shall be the speaking tongue of its age and on the other hand it should represent a coherent compound which links different spaces.

Negligence about the valuable and time honored spaces, mishandling the valuable physical spaces, presence of heavy city traffic, and discordance of buildings with these precious physical spaces has caused misunderstandings and incorrect interpretations and in better words these places are lost. By and large we can say the space, the event and the meaning are all misplaced along this axis and the *ZAND* axis in Shiraz is somehow a missing place, a place devoid of meaning, remembrance and truth reminiscent.

6 ZONING OF KARIMKHAN AXIS ON THE BASE OF IN SIMULTANEITY IN LINGUISTIC:

According to *De Saussure's* point of view and on the basis of simultaneity principle, spaces on the *ZAND* axis are zoned into three phases: historic, mid-age, new-age.

The simultaneity principle is one of the linguistic principles in which the simultaneity linguistics practice on the subjective relations which bond the symmetric elements to each other and develop a unified entity within the common mind of speakers of a lingual society.

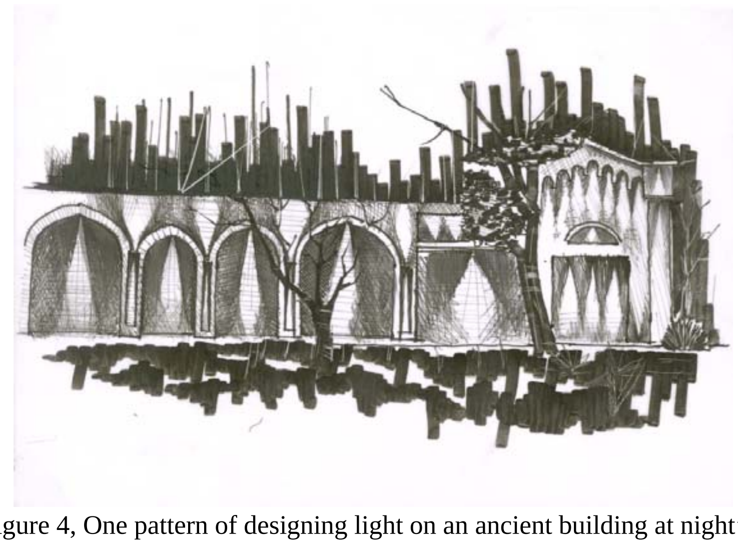
It's understood that in a lingual situation, everything is based on the relations. The spoken words because of their continuity establish relations between themselves which are on the basis of the time being linear and one-dimensional. This attribute of time makes the simultaneous pronunciation of two elements impossible and that’s why these elements are placed on the chain of a speech one after the other. These compounds with the pivot of the extension of time could be called a syntagmatic chain. The element on the chain is makes sense only when the next or previous (or both) elements are present.

KARIMKHAN-E-ZAND axis started to form before the *ZANDIE* era and is still being developed. According to the historic documentations and the current physical signs, it will be possible to study the mentioned zones within the *KARIMKHAN-E-ZAND* axis by categorizing the simultaneous spaces together (by their syntagmatic chain).

With a more distinct look at the three zones of the *ZAND* axis (historic, mid-age & new-age), these zones stand for components which a whole is made when they are put in a syntagmatic chain, so its necessary to define specific joints to join these components. This is where the joint such as a troublous urban node which functions as a link between the ancient and modern textures of the city becomes very important. In order to define the role of these nodes, one can say that the deep structures shall form the surface structures in a manner that enables the joint to demonstrate a smooth and proper transition between the two ages and of course the two places.

7 THE SATGES TO ACHIEVE PATTERNS:

In this part the reconnaissance of Alexander model are discussed which represents three divisions: elements, spatial relations and specially the context. According to what Alexander believes, each model has got components which constitute the structural elements of the context and the spatial relation establishes an atmosphere that plays an important roll in the living of a place used by people. Therefore each of the three elements of this model shall be improved and made more accurate. (Alexander 1977) As said before, Rapaport believes that the components which constitute the context are divided into three divisions: fixed elements, semi-fixed elements and moving elements (Rapaport 1988). This context could create a street in a scale or create a city in a larger scale, but these context themselves are totally formed in a unit cultural context. Since the perfect perceiving of these components is completely depending on the scale in which they are formed, and because the experimenter of a space shall move through the space in order to recognize the space, his/her present as active deciding factor obtains much importance. It's because the experimenter communicates with the environment by his/her cultural context or in better words his/her language. A famous city that leaves a good and memorable image in mind is the place that dedicates the sense of trust and power to the viewer and this is the issue that a good city shall represent. Thus individuals and also the societies must have a respective independence in order to be able to build their environment on the basis of their needs and requirements. If this didn't lead to the creation of the sense of place, it would at least help in this regard and this issue is on of the measures for sustainability of the city and the urban space. One other measure is the time, because time is and recognition of time is present underneath this physical environment.



'Figure 4, One pattern of designing light on an ancient building at night'

8 CONCLUSION:

If we review the ability of *KARIMKHAN-E-ZAND* axis experimenters in respect of recognition of time or the age when the buildings had been built, we can find out how the people are familiar with what we call historic hierarchy of construction and we can also find out whether people are able to distinguish different historical ages or not.

Afterwards we can discover the aspects that help them interpret such data or in better words we can discover anyone's time detecting parameters. We can find out which physical or environmental parameters (including the whole to the components) help them realize the roles and on the other hand what issues can cause them confusion in time recognition.

Finally by comprehending the points of view and by analyzing them, we could realize what should be done for the urban space of *KARMIKHAN-E-ZAND* in Shiraz to make it more interactive with its experimenters, or at least we can develop approaches in order to improve the current situation of this space or to plan the spaces to be built beside these time honored places more carefully and knowingly hereinafter.

The obvious thing is the importance of *KARMIKHAN-E-ZAND* axis in respect of its conceptual value because the conceptual, memorial and functional loads of this axis is an evident matter to anyone. By and large we should take two important hints into consideration:

When an old book which is subject of decaying loses some of its words or phrases which lead to difficulties in the reading of the book, there is a need to other words and phrases to be put adjacent to remained ones in order to achieve the meaning of a sentence. In addition when a historical text is to be published, it must be revised according to today's language in order to be understandable for the today's public. Therefore any policies having the aim to improve this axis scape shall precisely consider the historical alteration, the language of time, the omission of words and the revision of language as pointed out above.

REFERENCES

Alexander, C.et al, 1977.*A Pattern Language: Towns, Buildings, Construction.* New York: Oxford University Press.

Anderson, S, 1986. *On Street*, MIT press.

Chomsky, N, 1971.*Aspects de la theories syntaxique*.Paris: Seuil

Owen, J. H, 1987. *A Successful Street Design Process .Public Streets for Public Use*, Ed, Moudon, a, V .New York: Van No strand Reinhold.

Rapoport, A.1986.*Spatial Organization and the Built* Environment .Companion Encyclopedia of Anthropology, Humanity, Cultural and Social life .Ed: Tim In gold. Rutledge (UK)

The urban planning tools as quality control device for sustainable projects

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ABSTRACT: The sustainability defines and invests concepts that only a variety and integration of knowledge can be able to govern, and raise different scales in which it can be researched and caught up. In this context, the conducted experience of the Municipality of Rome is inserted which marks a very important step in an initial stage of innovation and sensibilities of the new mode to conceive and manage building participants. At the threshold of a new season of social housing the quantity requirements are placed side by side with quality research which privileges many aspects of atmospheric and technological quality and characterizes both the interaction and natural atmosphere.

1 INTRODUCTION

In the last twenty years the City of Rome, like all other administrative bodies of big European metropolitan areas, has had to confront, in many historic moments, the problem of living conditions and the problem of a strong demand for social housing in response to the housing needs of many parts of the population in marginal social or economic conditions.

The City of Rome confronted these questions through the actualization of the Plans for Populate and Economic Buildings in which was determined the quantity of buildings to construct; in particular the 2nd PEEP promotion in 1985 was redefined and refinanced many times until 2005. At this point the City, due to indications of regulations oriented towards the reduction of “housing needs”(Law 8 febbraio 2001, n 21) deliberated a new series of measures to put into action a true and actual Plan for Emergency Housing. To carry out this plan the City individualized different initiatives through which it promoted the transformation of 36 internal areas of its territory. In these territories it promoted the operational town planning, *the local urban planning - Zone Plans (Piani di Zona - PdZ)* which is preliminary to the operative projection of the building interventions and necessary infrastructure for the realization of new residential installation and their services. On these occasions, a capitalization phase of quality definitions of planners that were ready to go onto the territory in a way that supplies the citizen with an offer of services and residence that doesn’t satisfy only a question of quantity character, but also responds to the major ambient quality of the housing aspects, was supported.

To have the ability to carry out this proposition the Administration proposed an addition to the traditional structure of actual urban planning the “Code of practice” as a guide to the projection of future installations to realize; the Code will gather and put at the disposition of the planners and promoters of future installations, all of the indications and tools for the definition of a integrated project strategy, to control the global quality of the operators. In this way from the traditional indications of relative technical regulations to the realization of residential buildings it is possible to add a system of best practices, innovative indications, ambient quality and the realization of the energetic and ambient management of the sites and the buildings, with the knowledgeable use of technological solutions orientated towards the complex bettering of the performance of the building and of the urban complex.

1.1 *Needs of quantity and demand of quality. Strategies of qualification of the project of residence.*

The housing market always reports a situation of emergency due to the gap between the supply and demands of housing, in particular the social housing market. Facing a requirement of social housing at a relevantly low cost, with the ability to generate new situations of poor and profound social marginality, the market of residential buildings is proposing at the medium and high level, with factors of growth very relevant, to look at the private market and at a set of requirements and questions however resolvable.

In both cases, that which faces the social requirement of quantity character and that which articulates more the demand of quality in the privet market, the market responds with one equalizing and logic definition on the very traditional technological definitions and with typical solutions blocked - also due to current regulations- offers as an added value of extra-supply of space or equipment. Facing this solid report between supply and demand for housing on the market it is possible to define that the *needs of quantity* spring from the perception of the inadequate quantity of the existing housing stock, while the *demand of quality* springs from the knowledge of the necessity to establish a new report with the acclimating neighborhood, on the scale of the building and the urban complex.

The quality is not an objective characteristic, neither is it the qualifying characteristic of a product, instead it is the response to the expression of a need. Therefore a new question of quality presupposes one that is non satisfactory to the users in comparison to the actual building stock; when speaking of the quality of an architectural or urban project it's level of quality must be discussed and the level in which it responded to the need it generated.

It is possible to acknowledge two different levels of quality of a project: the definition quality and the realization quality.

The Community Administration intends to go exactly in this direction with the planning process for the included interventions in the new *Zone Plans*, where giving the guideline to better the project definition quality of the participants and the building quality level will create a more fine and complex control tool for the function of the expected performance. In this occasion all of the regulation indications up until today can also be made operative in an organic mode from the City with single measures and with the new regulations of the General Regulatory Plan with merit to acclimated sustainability of the building participants and also going over a certain traditional rigidness of the same urban tools with vigor.

The "Code of Practice" is configured as a supporting tool and direction for the realization and control of sustainability for building constructions, in particular social housing, proposing a highly integrated approach to the planning. The Code faces the revision of the answers to the housing requirements in terms of economic, social, functional, acclimation and energetic sustainability. These schematic propositions of typical innovative useful aggregations to the creation of urban spaces are analyzed in terms of both the comfort of public spaces, and as a functional and social mix in a way that obviates to the phenomenon of social and economic segregation which is typical of metropolitan peripheries.

The Code also faces the appraisal of appropriate technological and proportionate solutions to the typical buildings to realize in a way that doesn't make them different from the realized approach of the local promoters, asking a level of higher finalized technological performance for the acclimated support of the participants. The analysis of the innovative technological solutions for the realization of the residential buildings is studied deeply including the study of the construction materials to use in such a way as to orient in a knowledgeable way the choice of the constructive solutions and successive control in phases of realization through exercised management. With the same logic, the most appropriate system devices for efficiency in light of the indications of recent regulation matters of control and energetic management, were analyzed and valued. To support these indications the Code proposes an integrated model of analysis of the sites that are being intervened which comprehends all of the acclimated aspects and the characteristics of the single sites, to internally bring to the project and planning strategy, the indications coming from the natural and cultural characters of these places.

1.2 *Modes of integrating the coded solutions in the design of the building.*

The sustainability of a realization and the quality of the construction from the energetic point of view depends on various factors but for the most part how the building comes to be realized.

The reflections of the technological aspects of the building organism is reflected in the transformations, sometimes profound, to which it is assisted: the new material introduced in the market is added to conventional technology, the new and elevated performance levels asked for are confronted with the behavior and functional schemes to live contemporarily.

On one side is derived a performance of major operative clarity in the orientation the adoptable planning choices, and on the other side the importance of an explication of criteria that subtend the choice of the technological solution privileging an alternative in respect to the other. In particular, it is necessary to place particular attention on the definition of the superficial and border elements through the external and internal ambience outside building, which determine the requirement of the building and respond to the necessity of the users that will live there.

On this theme the most evident aspect is the emergence of acclimated and economic advantages that indicate not only the external ambience, but places first the user's quality of life. The adoption of new rules and new prescribed performances will bring a reduction of energetic consumptions for heating and air conditioning therefore a sensible reduction of electric bills (instillation of air conditioners, instillation of hot water production for hygienic use, electric installation) in the course of the useful building life.

On the other hand the atmospheric advantages are a direct consequence of the bettering the efficiency of the building and its installed systems: less consumption of combustibles in fact transform into less emission of gas into the atmosphere and a smaller impact of usable materials in the atmosphere.

The theme of eco-efficiency will be attacked head on instead of just from the side through the technological quality that the technical solutions will be able to guaranty. The importance of management in a building- evidenced through the objectives. The European advice of spring (OR. EN 7224/07 of March 8th 2007) is retaken by national (Legislative Decree 311/2006) and local regulations(Del. 48/2006 City of Rome)- underlining an ulterior element of reflection: the constantly growing role and weight of installations in the management of building stocks. Inserted in this discussion is the growing incident of necessary alternative installations to sustain buildings, looked at more from the point of view of initial costs than the dimensional impact of the same on area building objects.

The elevated requests to use renewable sources and the request to reduce energetic consumption and CO2 emissions into the atmosphere, translates mostly in the necessity of thinking towards the installation integration intended as a source to reduce the energetic demands of the country and of co-generation able to guaranty positive economic returns in the conduction of the buildings.

In this context, the existing ties between the installation systems and building wrapping systems assumes particular importance: every choice adapted in one of the systems weighs significantly on the projection and dimensions of the other.

The most evident aspect of evolution towards the regulatory picture to the government, is that of building activity and the beginning performance demand and of a virtuous behavior that can prime a "normal" practice of knowledgeable planning of sustainable energy and atmosphere.

This brings value not only for the immediate cost but also and overall for those projected in the future respect at any of the fundamental components such as health, efficiency, the length and maintenance that will continue to be valued case per case in single projects with merit to the urban context of the building.

The choice of the planner will definitely be that of finding the solution most adapted to the internal combination of many conditions, opportunities, and ties that are reference places to the climatic characteristics of the site in the evolution of the seasons during the course of the year, with a control of the external part of buildings in relation to their orientation and to the activity carried out in the internal part, which- in virtue of the errors of the past- attributes to the morphological quality of the buildings and the peculiar character that counter distinguishes the history of every place.

The problems of invested sustainability in fact is that more disciplinary ranges reserve and pretend that it is considered their interdependent reproach.

In light of the last consideration, atmospheric and technological requirements of the government as well as the answer to the same are both indivisible objectives which are attached in respect of coded architectural language and expressed to the single culture.

Within the innumerable contemplated aspects in the concept of project sustainability, the aspects that relate to the different needs of every country (town) is not diminished. This theme which in the past was in part hidden, lead those which were problematic so that the actual recovery activity of the buildings, tries in a diffused manner to overwhelm.

The monotony, the repetition and still the absence of attraction of the buildings in the recent past, as much in Italy as in other European countries, are the evident results of an approach to the extirpated project of the text in which it was inserted.

In prospective of this "virtuous" planning orientation in the residential buildings, new realization is assisted by research of coverings which are characterized by innovative forms under both the technological and formal aspects that push the planners towards an attentive analysis and flexibility experiment in concepts of both research of new rules for the coded distribution of flexibility concepts and in research of the coded distribution of habitable spaces, lastly importing often constructive techniques of other types of buildings.

The technological transfer of some solutions coming from analogous building sectors is conducted from an increment of its repertoire and the performance of the systems that are offered, to the introduction of material that is more or less sophisticated and has the ability to satisfy the performance levels with a minor impact on it's environment but not always easy to control in time.

In this historic period, it is renown in fact that there is an industry of construction with the ability to always offer new products which gives the planner many choices from a catalogue of elements which are more or less complex.

Following this last consideration derives the fact that the more the components become complex the more they are composed of single layers, or sub-elements; on the other side it is stabilized so that as much more of the technical element performance is the sum of the layers single performance and this will be mostly important to control the final technological quality. It will also be necessary to verify an analytic method, which will be the performance which responds better to both the need and actions that define the needed picture of the residence, and the priorities with which computably design the objects of the effective sustainable plan.

This is then observed as the external wrapping of one of the appointed principle places to respond to the building project's sustainability. At the same time the elements that compose it are called to satisfy in a coherent manner all of the aspects that are of volumetric and spatial composition of the building was not able to respond.

The research of the wrapping elements has therefore conducted, at a moment of reflection and analysis, the morphological characteristics and the specific performances of the significant and adoptable thought solution.

Due to the large variety and complexity of the systems and elements it is believed effective the internal predisposition of the "Code of Practice" as a tool of complex-methodological guide and support for the choices to carry out, through which individualize and at lastly prefer the thought solution which is most adapted to the internal technology actually available.

The new manner to think of technological sustainability is looked for in the acknowledgement process of the values of architecture and in the adoption of a new planning method appropriate to the transformation of the natural environment in man-made environment turned to a new more knowledgeable community.

A similar approach modifies the projection of the technical elements, which must be thought of not only as a connection and or separation from the other elements of the building system, but also effectively "integrated" thanks to an interdisciplinary involvement of various specialists involved in the planning process.

1.3 *Construction materials. Product and process innovation for residential buildings.*

The "Code of Practice" for the *Zone Planes* of the city of Rome previews a reasoned appraisal of construction materials to employ in the realization of the participant; the appraisal criteria doesn't aim to construct an abacus of it's materials or suggest less use for these buildings, but intends to supply tools to the person who will plan and realize these buildings and to chose the material and the constructive solutions in a way to give an answer to a system of technical individualized requirements as determined for the effectiveness and the sustainability of the proposed solution. The choices to use less of a determined product comes accompanied through a few different criteria for selection which are defined to satisfy the necessity to obtain good performance of the physical-technical type but at the same time guarantee a low impact on the atmosphere.

The parameters of the proposed appraisals are constituted in part by measurable elements, comparable to the quantity level, and in part derive from the comparison given numeric consideration of quality character.

The appraisal is computed on materials able to guarantee performance of good thermal and acoustic isolation; the materials are entrusted and capable of creating comfortable atmospheric conditions in the internal habitation space at a perceptive and sensorial level. In particular, the choice proceeds through three successive levels.

The first level is through the reading of numeric value of thermal conductivity preferring material of low value of thermal conductivity which obtains technological solutions with greater insulator capacity.

The second level examines the volume mass of the material. In the climatic conditions of Rome, a high amount a mass guarantees comfortable internal living conditions contributing to the happiness of energetic consumptions, supporting and in certain cases rendering superfluous systems for cooling the atmosphere.

The thermal inertia or mass effect uses the physical property of the materials to increase the time (thermal lag) that the heat wave employs to cross the walls; this produces a stabilization of the temperature also during the day. In good thermal behavior materials with big volume mass is associated with better power for less sound. The attenuation of noises, measured in decibel, grows in relation to the interposed mass between the beginning of the noise and the atmosphere to protect. A good capacity of acoustic material isolations corresponds with a major level of internal comfort and livability of the space.

The data relevant to volume mass is moreover connected with the regimen of preferential use. This regards the difference of performance offers in case of either summer or winter seasons. Internally, the “Code of Practice” has been tasked as a preferential regimen of use in relation to the hot season. The realized buildings in the city of Rome, as in Italy and the center-south of Europe, due to climate conditions of the river basin of the Mediterranean, which is characterized by mild winters and hot summers, presents more of a necessity to defend itself from low temperatures, the need to minimize the use of installation of artificial air conditioners during the summer season and finally to contain the energetic consumption and realize good internal conditions of comfort.

The third level of selection is based on LCA (Life Cycle Analysis) and the PEC value primary energy consumption. Through the LCA the complete life cycle of the material is valued, from the supply of the first materials to the realization of the concluded document manuscript; to value the LCA of a material multiple aspects are examined, some of which can’t be directly measured and confronted. In particular, the force of primary energy (PEI) offers a partial value of the product’s like cycle. This constitutes an ulterior parameter of comparison; it is always preferable, when possible to use a material that is able to develop a low consumption of energy in productive phases, because of the total minor impact in the surrounding atmosphere. Some synthetic insulators for example even having a good level of performance of thermal isolation are characterized by a high consumption of primary energy: in their place should be preferred insulators of natural (fiber glass) or vegetable (wood fibers) minerals.

The three level of evaluation sum up internally their elements of quantity and quality nature, they don’t answer univocally to the demand of what would be the best situation; these supply some indications which give the possibility to complete a choice at the end and to have the ability to realize technological solutions for the *Zone Plans* supporters for the principles of sustainability and biocompatible buildings.

1.4 *Systems of integrated sustainability*

The “Code of Practice” for the *Zone Plans* of the city of Rome previews a reasoned appraisal. A good architect depends on the knowledgeable energetic choices. The role of the architect, in this optical, has to necessarily make itself larger towards the planning of integrated type, even if the specific object of the projection is the planning of the city or the scale of the industrial design. Underlining the importance until the end of a logic planning in terms of analysis and requirements, request appraisals, optimization of performances is to considered incoherent anything in architectonic participation that doesn't look for an equilibration between the building system and the atmospheric system in which and on which it burdens.

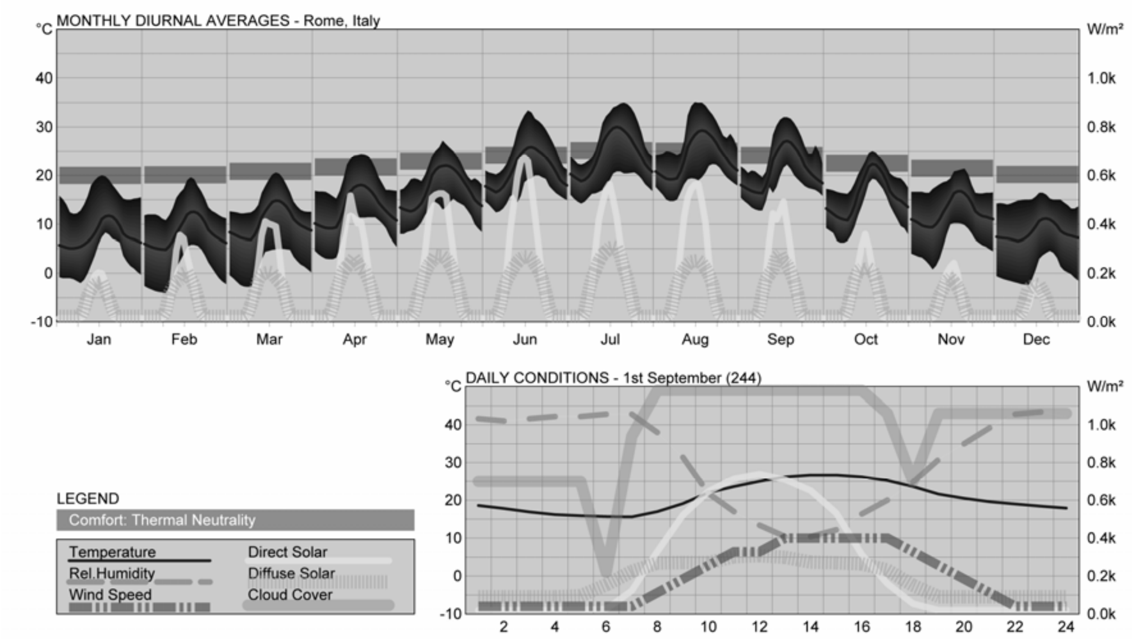

Figure 1.Climate evaluation diagram in Rome. The multi-parameter analysis of the factors represents the correct interpretation of the climatic phenomena and the synergies between each other.

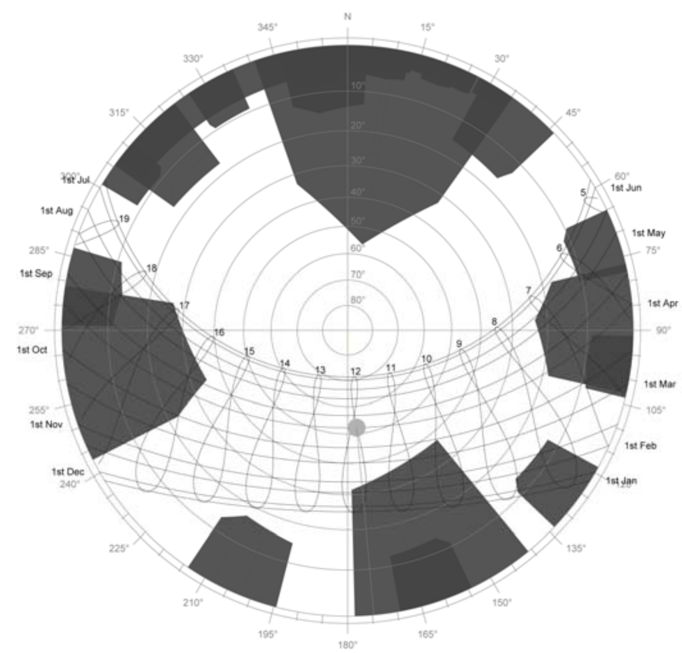

Figure 2. Example of punctual application. Analysis shows on polar solar diagram the direct influence among the point of analysis and the urban context represented by the surrounding buildings, translated in terms of factor of shadowing. Software used for the realization of the shadowing masks: Ecotect.

The experience of the “Code of Practice” for the *Zone Plans* of Rome explicitly inserts into this logic: organized sequence of work phases in which every option either punctual or systematic is a consequence of the analysis of the climatic variables and their possible synergic interaction in key projects. Parameters, climates, typical models, conformed technical solutions, requirements, technical norms, synergy and compatibility matrices all assume a wide internal value of this research, in full coherence with the objectives of the program.

In specific themes of methodology, as revealed with the climatic analysis, the use of Ecotect software is placed side by side (with much attention of the Weather Tool module) with the traditional bibliographic research.

The idea on which the entire study of the “Code of Practice” is structured is the following: analyze the potential of an ambient building system, individualize the eventual compatibility or critical with the technical possibilities present on the market. A fundamental role therefore is to assume the same concept of compatibility, intended in its own wide sense, technical, economical and destination of use which is relatively and normatively tied. To delineate a process in this sense imposes inevitably a preliminary survey in merit of the characteristics of the urban climate, but implicitly signifies also to inquire the technical performance of the functional models of wrapping buildings successively defined as compatible.

The objective is to draw from the valid project indications on both a scale of the neighborhood and the scale of the single building: which is not limited to one vision with the phenomenon in general and quality keys, but to suggest, actually impose a specific deepening where it is verified the conditions of particular attention. These intentions are translated into concrete; by means of punctual appraisal the adoption of methods that verify and consolidate for what that prevalently concerns the solar radiation. It is a merited choice to deepen that climatic parameter in other regions: in the first place the solar radiation is configured on a scale of the whole building, as major significance in relation to passive performance of closure packets and to the potential in terms of unduly influenced solar systems. In support of this position it is necessary to underline the analysis of climate data already on the urban scale, for example, the code has concurred from the beginning to exclude an approach on the theme of energetic optimization in keys of exploitation of Aeolic systems; the reviewed data clearly show that the Aeolic phenomenon are substantially negligible for what concerns intensity and frequency in the City of Rome. The analysis of solar radiation at a complex urban level gives quality indications of external spaces for buildings of divided public spaces of the project.

The promotion of an integrated approach to the sustainable projection is translated therefore in the suggestion of multi-level intervention strategies that take into consideration the possible projection interactions between all of the elements of the interaction between the urban and natural atmosphere.

REFERENCES

Arbizzani, E. & Civiero, P. 2007. General overview of the problems, needs and solutions in the Italian urban building envelopes, in Almeida M., Hadjmichael G., Melgaard E., Verhoef L.G.W. A (eds), *Improving the quality of the existing urban building envelopes – Needs*. (vol. 3, pp. 69-79), Amsterdam: IOS PRESS.

Aste, N. 2002. *Il fotovoltaico in architettura. L’integrazione dei sistemi a energia solare negli edifici*. Napoli: Esselibri

Bazzocchi, F. (ed.), 2003. *Facciate Ventilate. Architettura Prestazioni e Tecnologia*. Alinea: Firenze

Biondo, G. & Al. (eds) 2005. *Abitare il futuro: Città, quartieri, case*. Bologna: BE-MA

Bruno, S. 2001. *Progettazione bioclimatica e bioedilizia*. Milano: Il Sole 24 Ore

Burroni, E. 2006. Eco-consulting. Sostenibilità su scala urbana ed edilizia *Costruire in Laterizio* 109

Campioli, A. & Ferrari S. &Lavagna S., 2006. Gli involucri edilizi e il rendimento energetico degli edifici, *Costruire in Laterizio* 111: 64-69.

Cappelletti, G. 2007. *La nuova normativa sul risparmio energetico; il Decreto Legislativo 192-2005 e le risposte sperimentali e pratiche delle strutture in laterizio. La Gazzetta dei Sola* 37.

Civiero, P. 2006. Riqualificazione dell’involucro dell’edificio. in: Esposito M.A. (ed). *Tecnologia dell’architettura: creatività e innovazione nella ricerca*. Firenze, Firenze University Press: 219-225.

Civiero P. & Brunoro S. & Di Giulio R. 2007. Techniques for adaptations of structures of a multi-stories family house in Florence, in: Di Giulio R., Bozinovki Z., Verhoef L.G.W (eds). *Improving the quality of the existing urban building envelopes – Structures*, (vol. 4) Amsterdam: IOS PRESS: 27-36.

Colombo G., 2006. *Lo stato dell'arte nella progettazione degli edifici passivi*, Firenze, Alinea.

Commission of yhe Council The European Parliament, 2004. *COM(2004)60 final Communication from the Commission of yhe Council The European Parliament, tha European Economics and socila committee and the committee of the Regions, Towards a thematic strategy on the urban environmen*t, Bruxelles: Commission of yhe Council The European Parliament

Comune di Ferrara. 1998-2006. *Regolamento edilizio del Comune di Ferrara*. Ferrara: Comune di Ferrara

De Santoli L., 2006. *Analisi del ciclo di vita del sistema edificio-impianto*, Roma, Palombi.

Decreto Legislativo 19 agosto 2005, n. 192 "Attuazione della direttiva 2002/91/CE relativa al rendimento energetico nell'edilizia". Gazzetta Ufficiale n. 222 del 23 settembre 2005 – S.O. n. 158

Decreto Legislativo 29 dicembre 2006, n. 311 "Disposizioni correttive ed integrative al decreto legislativo 19 agosto 2005, n. 192, recante attuazione della direttiva 2002/91/CE, relativa al rendimento energetico nell'edilizia". Gazzetta Ufficiale n. 26 del 1 febbraio 2007 – S.O. n. 26/L

Di Fusco, A. 2006. Prestazioni termiche e comportamento ambientale di soluzioni tecniche di involucro in laterizio. *La Gazzetta dei Solai 35*

Environment Park. 2001. *Linee guida per la sostenibilità nel progetto, nella costruzione e nell'esercizio dei Villaggi Olimpici e Multimedia,* Torino*:* Environment Park – Torino 2006

European Parliament. 2002. *Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.* Bruxelles: European Parliament

Franco, G. 2003. *L'involucro edilizio*. Roma: EPC

Gallo, C. 2000. *La qualità energetica e ambientale nell'architettura sostenibile*. Milano: Il Sole 24 Ore

Gargari, C., 2006. Laterizio: energia e qualità dell'abitare, *Costruire in Laterizio* 112: 58-63.

Grosso M., & Peretti G.& Piardi S. & Scudo G. 2005. *Progettazione ecocompatibile dell'architettura. Conectti e metodi, strumenti d'analisi e valutazione, esempi applicativi*, Napoli : Sistemi editoriali

Lepore, M. 2004. *Progettazione bioclimatica in ambito urbano,* Roma: Aracne

Masera, G. 2004. Residenze e risparmio energetico, Milano, Il sole 24 ore.

Medola, M. 2007. La massa dei laterizi e il risparmio energetico, *La Gazzetta dei Solai* 38

Perago, A. 2006. *Progettare le chiusure verticali,* Rimini, Maggioli

Rava, P., 2007, *Tecniche costruttive per l'efficienza energetica e la sostenibilità,* Rimini, Maggioli.

Regione Emilia Romagna, 2000. *Requisiti volontari per una qualità ambinetale degli interventi edilizi. Relazione tecnica,* Bologna: Regione Emilia Romagna

Regione Toscana, 2005. *Linee guida per la valutazione della qualità energetica ambientale degli edifici in Toscana, Firenze:* Regione Toscana

Regione Toscana, 2005. *Elenco base dei materiali per l'edilizia sostenibile, Firenze:* Giunta Regionale Toscana - Direzione Generale della Presidenza - Area di Coordinamento Programmazione e controllo - Settore Programmazione dello Sviluppo Sostenibile

Sala, M. (ed.) 2000. *Schermature solar*i. Firenze: Alinea

Szokolay, S. 2004. *Introduzione alla progettazione sostenibile,* Milano, Hoepli

Torricelli, M.C., & Gargari, C. & Palombo, E. 2007. Valutazione ambientale nel ciclo di vita dei prodotti in laterizio. *Costruire in Laterizio* 116: 60-67.

Trevisi, A.S. et al. 2007. E*fficenza energetica in edilizia*. Rimini: Maggioli

Urban rehabilitation with sustainable principles: the case study of Montefalcione, South Italy

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ABSTRACT: The paper describes a methodology employed for the urban rehabilitation of small historical centers in South Italy, with sustainable principles. The methodology, mainly consisting in a deep analysis of environmental factors and urban features of the town itself, had also led to a design approach which takes into account both users' needs in terms of comfort and health, and local sustainable requirements. The investigation procedure had been outlined and the idea of matching performance of the place with users' requirements had been experimented, so as to reduce to the minimal impact any eventual aggressive intervention, and to satisfy at the maximum the citizens' social and cultural needs. A sample of the design methodology has been explained for the selected areas, with children, elderly and middle aged citizens' facilities.

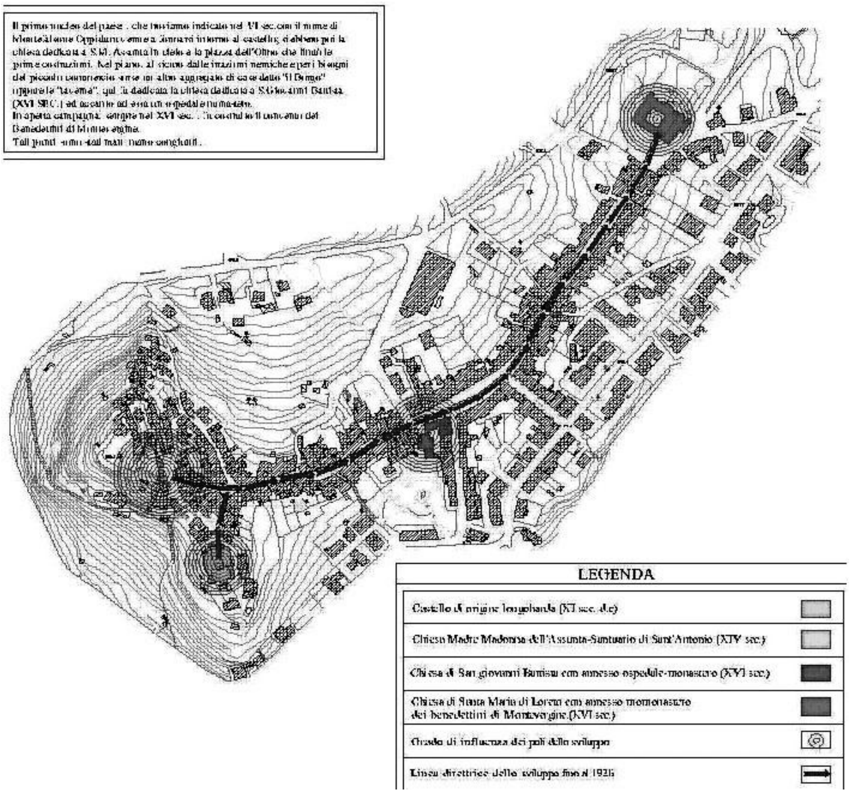
1 INTRODUCTION

As it is well known, the quality of urban environment demands great effort to be maintained, for two main reasons: the first regards the eventual obsolescence that particularly historical centres present in terms of renewed living requirements, and the other one is the present way of providing comfort in towns.

Being now the sustainable aspects indispensable and unavoidable during all the processes of transformation of the environment, even renewing and rehabilitating the urban life of small historical centres need to be done with respect of ecological principles and with great care so as to insure a different way of providing comfort indoor as well as mobility and routing outdoor. Only with these principles a real improvement could be achieved as far as the quality of life is concerned. In order to avoid traffic and factories, main responsible of outdoor pollution, within the roads and squares of small towns, different way of development is required which will exclude the big expansion, such as commercial centres and big maxi cinemas and theatres, but will include the facilities for social life, children playgrounds, young people meeting points, elderly areas and sport fields. This approach is the sole possible means for really improving the quality of life and granting a future for small historical centres, especially in the south Italian areas, where no longer young and work-aged people are encouraged to live, for there are no chances of a future carrier as artisan or as any other role. The reality is now projected towards a modern American style life model in which no other aim is important than the shopping, the tours with the private cars, the big cinema and pub where to drink and smoke various substances. If the future of life in small Italian towns has to become like this, not only they will lose their identity, as far as the idea of national culture and art aspects are concerned, but also in terms of material culture and architectural outlook. In fact in order to adapt the small and narrow streets of medieval towns to the aforesaid requirements it will be necessary to transform them greatly and to destroy part of their urban values and identity. We believe on the other hand that the only way of interpreting the sustainable development of small towns in the Italian south reality is in fact that of trying to re-establish the actual economy of arts and craft and local cultural identity, through an ecological and as much natural as possible design, aimed at both eco-sustainable and bio-compatibile solutions, employing green, water, sound, wind and sun as means of urban life improvement.

2 THE CASE STUDY: MONTEFALCIONE HISTORICAL CENTRE

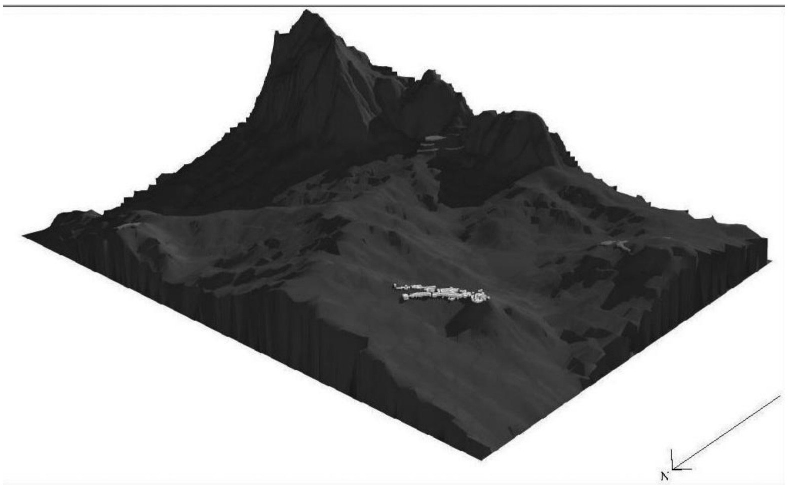
The case study, selected by the student Luca Roberto for his degree thesis, is in fact located in the south Italian area; the small town taken as sample of the new methodology of urban ecological design is Montefalcione, near Naples, where the historical centre still presents most of the original architectural characters and not great changes had occurred since the earthquake of the 1980.



Picture 1 - Historical development of the Town

As far as the reasons and the history of the original settlement of this town are concerned, we know that the first nucleus of the fabrics, called "Montefalcione oppidum" since the sixth century, was located around the castle; lately the church dedicated to Saint Mary and the "Olmo" square restricted the limits of the building part of the town itself. Then, for commercial needs, in the flat area near the castle protected by the enemies, another small group of houses aroused, with the name of "Borgo". Here the church dedicated to Saint John and close to it an hospital were built around the sixteenth century, and in the same period also a small cemetery of the Benedict fathers grew in the open country not far from the "Borgo".

Finally slowly and step by step all the territory in between the various villages had been filled up, so as to join the original nucleus, the "Borgo", and the cemetery in the present town of Montefalcione.



Picture 2 - Territorial Overview

Nowadays the town shows the shape of a long sword, with the principal road in the middle, going from east to west, and the buildings along it, with the major part of them on the south side of the road itself. In the extreme west spot of the road the built environment expands, where the original nucleus was settled around the castle..

3. THE CONSTRUCTIVE TEXTURE OF THE TOWN

From the geological point of view, the settlement is included in a region near the central southern Apennine chain. In this sector of the chain a great variety of sedimentary and some effusive and piroclastic rocks are available.

Diffused in all the Campania region are the piroclastic with discrete technical qualities such as the grey Campanian Tufa stone and the yellow Neapolitan Tufa stone.

In particular the main geological formation of the area are the Jurassic and Cretaceous limestone, the sedimentary and the volcanic materials; the latest can be found in the shape of great tufa bank, both coherent and incoherent.

Picture 3 - Traditional Architecture

From the study of the building characters of the historical centre the presence emerges of various constructive typologies, strictly linked to the geological nature of the territory and to the expertise of the local craftsmanship. The main buildings that define the texture are made up with a peculiar constructive system, which is continuous and stoned, with vaulted ceilings in stones, structural timber floors and tilted roofs with wooden structure.

The main element that provides a specific identity to the historical centre of Montefalcione is the building envelope; the constructive system is in fact defined by the envelope itself, all in massive stone wall. The aspect of the village is then distinguished by the wall texture and by the variety of colours of the stone blocks. The walls in limestone are generally realized with non squared blocks, except for the corners, made on work with the simple mortar system. The Tufa stone, which represents the final cycle of the eruption of circa ten, twenty thousands of years ago, can be considered as a surface resource. This material can be employed still now for it is cheap, easily workable and simply put on site, mainly for the construction of small buildings.

4 METHODOLOGY OF THE RESEARCH

After the latest ecological approach on building art, the intervention of rehabilitation, both at the urban and the fabric scale, has to be considered as an operation aimed at improving environmental and fruition performances. According to these principles, the evaluation and reading method of the case study is oriented to create in the open spaces of the urban centre (squares, roads, green areas…) the best conditions of comfort for a correct fruition all the year along.

This method previews a series of analyses and investigations aimed at building a detailed frame of knowledge about the behaviour of such external spaces as far as the thermal comfort is concerned.

Comparing the environmental factors of the site (climate, geology, morphology, and so on) with the building choices of the case study (materials, constructive systems, texture and so on), it has been possible to define clearly the way for intervention in a sustainable urban rehabilitation, employing a great number of bioclimatic advices.

In particular, in order to design correctly open spaces which will be comfortable both in winter and in summer, it has resulted fundamental to process a very careful analysis of the shading and ventilation, carried out by means of various investigation tools (visual survey, simulation, and so on).

Picture 4 - Shading Analysis in Winter (2 p.m.)

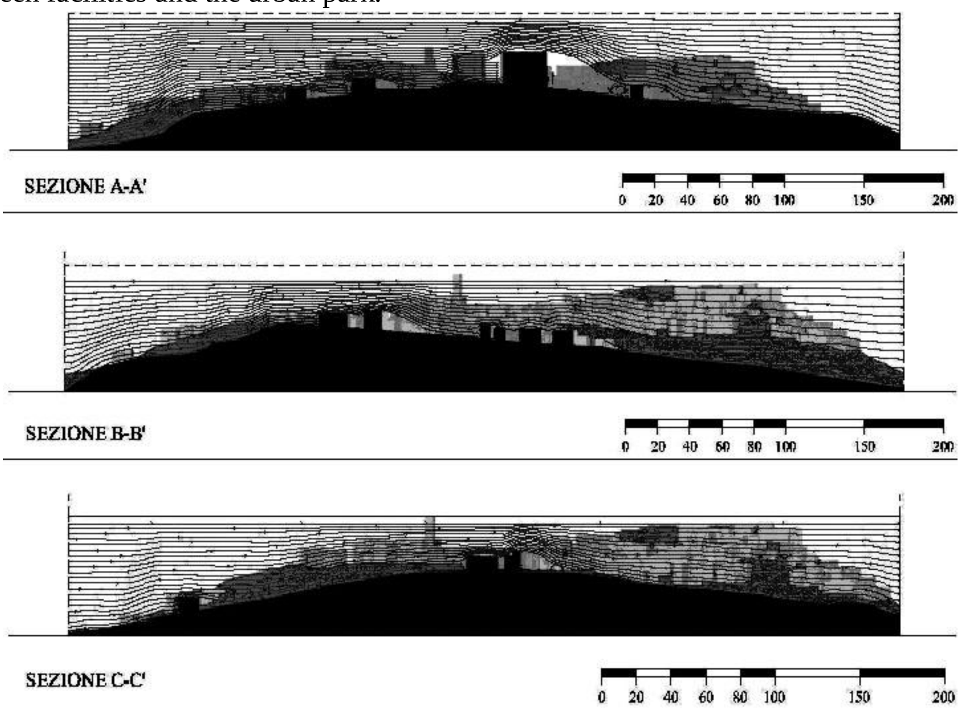
The result, processed through the graphical instrument of the mapping, had clearly shown with differently coloured areas, the less or more sunned zones, and those more exposed to winds. The outputs of this analysis have then been combined together so as to obtain a final and more complete mapping regarding the winter and summer comfort conditions.

Thanks to this method of work, four different areas of study have been selected as sample of the town situation which, as far as climatic and land reasons are concerned, better performed to an action of eco-sustainable urban rehabilitation. The following step was the identification of the existing facilities and services (cultural, social and for free time) in the town of Montefalcione, and then the compilation of a list of the lacking ones as main elements around which the rehabilitation design of the aforesaid areas could have helped to develop.

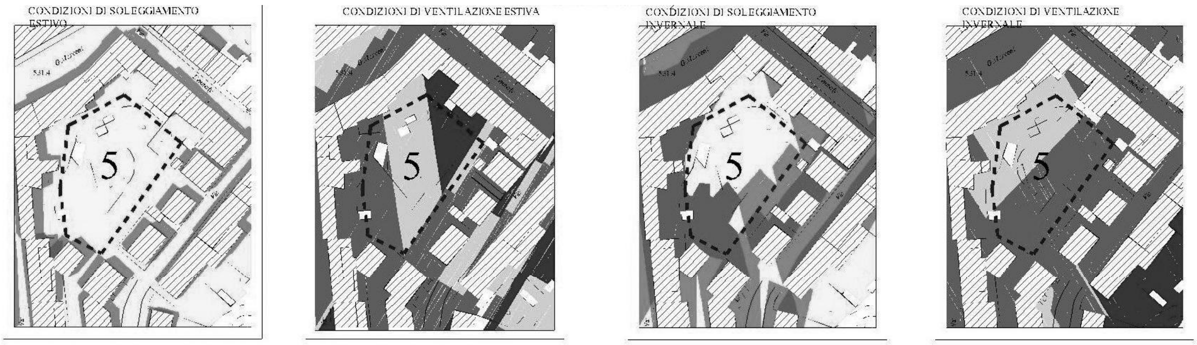
In the following four areas the design methodology had been applied: the local marketplace, the sport areas, the green facilities and the urban park.

Then for each of them the main users' activities had been defined, and a number of requirements had been associated, for both winter and summer situation, as fundamental for a right fruition of the spaces, according to their use destination.

By means of shading and wind analysis, the satisfied requirements and those not been responded have



Picture 5 - Winter Wind Analyse (South East) been established for each area and activity, thus creating an useful guide and verification tool of the essential interventions for an urban renewal according to the principles of the environmental sustainable action.

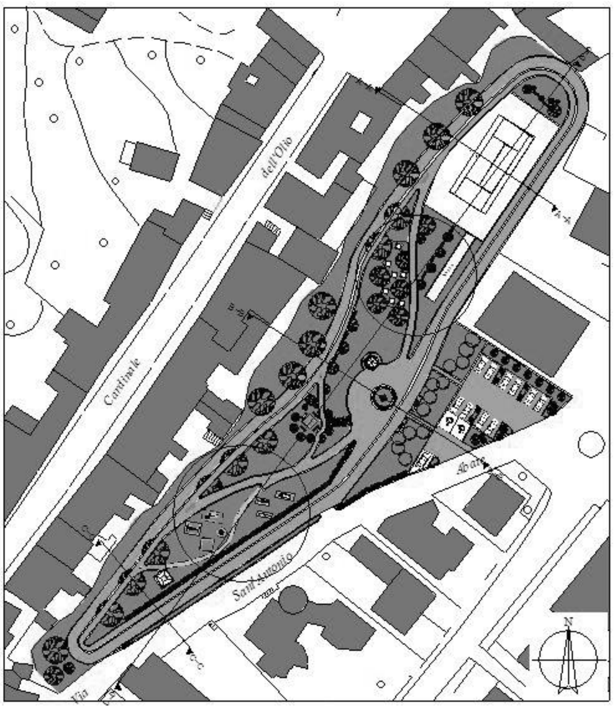


		Periodo estivo		Periodo invernale	
Destinazione d'uso pevista	Attivita' da svolgere	Requisiti estivi attivita'	Requisiti invernali attivita' soddisfatti-non soddisfatti	Requisiti invernali attivita'	Requisiti invernali attivita' soddisfatti-non soddisfatti
verde attrezzato	gioco bambini gioco anziani	Ombra	No	Sole	Si
	pertinenza centro culturale	Ventilazione naturale	Si	Protezione venti freddi	No
	pertinenza residenza	Ombra,ventil.naturale	assenza di ombra	sole,protez.venti assenza umidità	presenza di umidità in alcune zone

Picture 6 - Needs and Behaviour for the Area 5

Thus, for example, for the area defined as "Green Facilities", the selected activities were four: children play, elderly occupation, cultural centre and housing. The requirements for the three first activities have been identified with Shading and Natural ventilation for summer, and solar gain and cold wind protection for winter; for the latest activity the requirements of Shading and Natural ventilation in summer, and cold wind protection, sun and humidity control for winter have been considered unavoidable.

5 DESIGN FOR URBAN REHABILITATION WITH SUSTAINABLE PRINCIPLES



Picture 7 - Design of the Area 4

The final rehabilitation design has then begun specifically from the results of the just described deep analysis and evaluation, starting from the location of the activities for each area, according to the satisfaction of the introduced requirements. When one or more requirements had not been responded, the rule of the design had been actually that of filling these gaps by means of environmental technological solutions, aimed at employing local and natural material as well as reducing the impacts as much as possible.

In fact, the protection from cold winds had been achieved through a vegetable barrier of the evergreen Laurus Cerasus, located according to needs, while in order to guarantee a good level of winter solar radiation and at the same time a good shading barrier during summer, a number of Poplar lines (with falling leaves) had been proposed on the south side near the activities and the houses.

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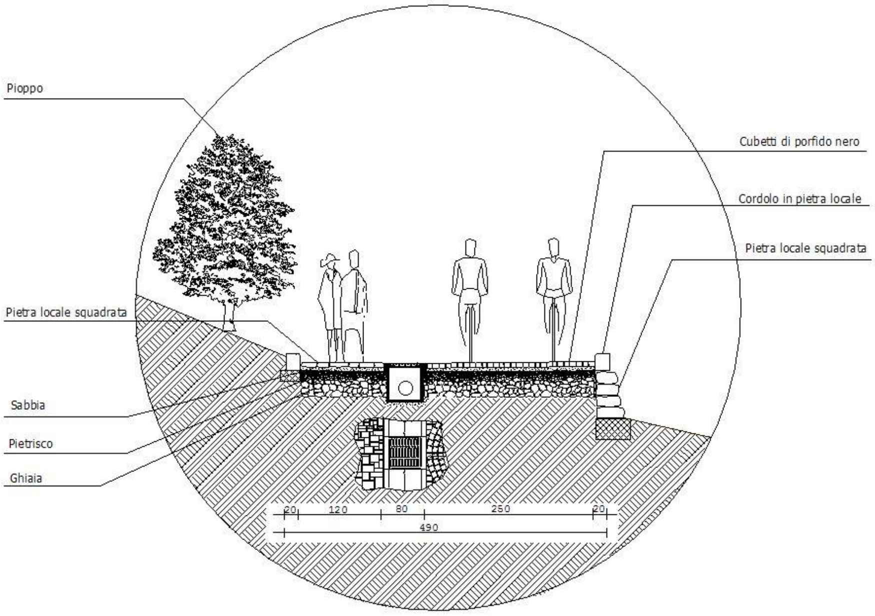
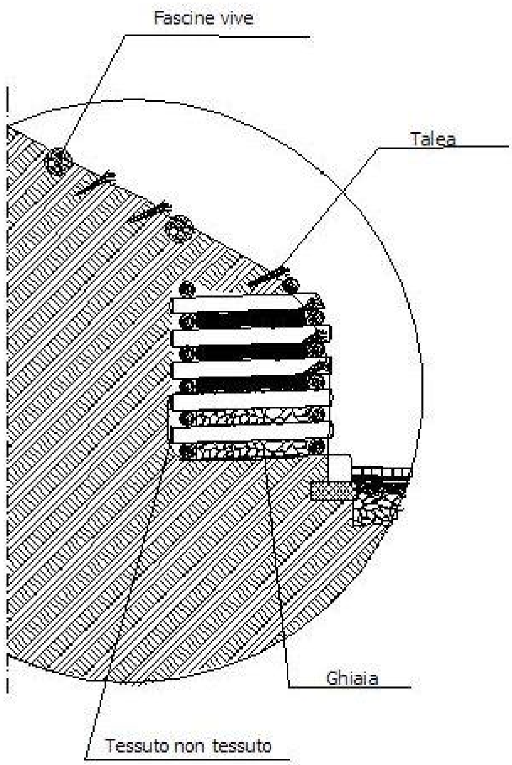


Picture 8 - Section of a road in the Area 4

The routeing has also been re-designed taking into account the morphology of the ground, so as to obtain an harmonic insertion into the environmental context, and thought according to users' needs, by distinguishing pedestrian and riding routes, also with various floor selection: local limestone slab for the first and volcanic stone cubes for the second.
As far as the containing works are concerned, natural engineering methods could be applied, such as the so called "crated wall", where the structural function has been provided by timber beams together with living plants. In order to guarantee the fruition in the meeting points and in the small squares during summer, some fountains have been proposed, aimed at providing the effect of evaporative cooling. Moreover a system for gathering rain water had been outlined so as to irrigate the green surfaces. Latest, in order to reduce the atmospheric pollution due to car use and to facilitate a different relationship with the built environment, the historical centre had to be employed mostly for pedestrians.



Picture 9 - Section of "crated wall"

Picture 10 - Design of the Areas 2-3

6 CONCLUSIONS

The method here outlined for the re-design of this small historical centre in south Italy, can be proposed as a means of sustainable approach to urban rehabilitation, as far as the investigation analyses are concerned, such as the shading, the wind and the morphological situation. But it can be considered also as a tool for responding to social and environmental requirements of citizens, because the idea of controlling the correspondence between requirements of each future activity to be inserted and the performance of the open spaces, as they presently appear, could actually save the historical centre from a big aggressive transformation of its image and identity, and at the same time provide comfort and pleasure to users. The small modifications proposed with this method, aimed mainly at reducing environmental impact and at improving safety and health for the citizens, should also carefully be selected in harmony with the existing historical features of the town, thus saving the signs of the local material culture.

REFERENCES

Fitch, J. M. (1980) *La progettazione ambientale*, Muzzio, Padova.

Francese, D. (2002) *Il benessere negli interventi di recupero edilizio*, Diade, Padova.

Marat-Mendes, T. (2003) *Planning the sustainable City*, in “The planned city”, Proceedings of the ISUF International Conference, Uniongrafica Corcelli, ed., Bari

Pagliuca, G. (1926) *Monografia Storica di Montefalcione*, Ed. Premiata Tipografia Natale NEPPI, Viareggio.

Energy and resources, material choice and recycling potential in low energy buildings

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ABSTRACT: This paper presents three Swedish residential low energy buildings regarding the total need of energy in a life cycle perspective, the environmental impacts, effects of choice of material and the recycling potential. The calculated energy need for operation (space heating, electricity, hot water) was in average 50 kWh/m^2 floor area per year. Simulations were made with four electricity mixes. For a service life of 50 years, production and transportation of materials accounted for 50-60 % of the impacts in the case representing the actual energy mix. This changes the prevailing picture that operation accounts for the main part of energy use. The recycling potential was about 35 %. Choice of materials affected the energy for the material part about 15 %.

1 INTRODUCTION

Total energy use in a life cycle perspective has been studied throughout the international community in order to identify the phases in the life cycle which are most important to, improve. The life cycle includes material production (cradle to gate), transports, building processes, operation and maintenance. Numerous studies have shown that operational energy accounts for about 85–95% of total energy use in dwellings during an assumed service life of 50 years.

A few studies on low-energy residential buildings have also been carried out [Nielsen 1995, Feist 1996, Winter 1999, Kohler 2004]. Nielsen and Winter show that the embodied energy in Nordic dwellings may account for as much as 40–60 % of total energy use, however these studies are limited to only energy in terms of MJ. In the study by Kohler, the embodied energy in German dwellings accounted for 30-40 % during a period of 80 years. Kohler also studied the global warming, acidification and radioactive waste when UCPT [1] electricity-mix was used. The material part accounted for 30-45 %, 35-53 %, and 10-15 % respectively.

There is now a large interest in low-energy buildings and passive houses. In Sweden, the first passive house was built in 2001 and in year 2008/2009, it is assumed to be about 700 apartments in low-energy buildings or passive houses. There are several reasons that aspects such as environmental impacts, effects of material choice and the recycling potential are of great interest to include.

Different energy sources cause different environmental impacts. In Sweden, fossil fuels for heating in the building stock has been exchanged to district heating and accounts today for only about 11 % compared to about 26 % in the early 1990s [SCBa].

[1] UCPT is the Union for the Co-ordination of Production and Transmission of Electricity. Countries in the union are Austria, Belgium Germany France, Greece, Italy, Luxembourg, Netherlands, Portugal, Spain; Switzerland and most of the former Yugoslavia.

The choice of material is likely to affect the building's energy need for the material part. Scheuer concluded that high-embodied energy components are often subject to a wide range of replacements [Scheuer 2003]. A comparison of beams at the new airport outside Oslo showed that the total energy consumption in the manufacturing of steel beams is two to three times higher, and the use of fossil fuels 6–12 times higher, than in the manufacturing of glulam beams [Petersen 2005]. Buchanan suggests that increasing the emphasis on wood as a building material could have significant implications for global energy requirements and global carbon dioxide emissions [Buchanan 1999]. Studies of Dutch residential construction revealed that an increase in wood use could reduce CO2 emissions by almost 50%, compared with traditional Dutch construction [Goverse 2001].

There is an increased interest in recycling and the recycling potential in the society. The potential energy saving in material production was studied in three building designs [Gao 2001]. In each design, a maximum use of recycled materials and products were assumed. The result indicated that energy use for material production decreased by about 25%, compared to a case where recycled materials were not used.

Studies concerning embodied energy in a life cycle perspective raise several questions. What is the total energy use in a life cycle perspective in low energy buildings? What is the relation between the environmental impacts from material production and from heating? In the new generation of low energy houses, the passive houses, the optimal goal is that no energy for heating is needed. This means that all bought energy will be electricity. To what extent can embodied energy be reduced with simple material substitutions? How do such substitutions affect the recycling potential?

2 AIM OF THE STUDY

The aim of the study was to investigate three low energy-efficient dwellings in Sweden regarding energy need in a life cycle perspective, environmental impacts, the recycling potential and how the choice of material may affect the energy need for material production.

3 STUDIED BUILDINGS

The three studied residential buildings are presented in table 1. The calculated energy need includes energy for space heating, electricity and hot water.

The buildings are interesting as the low-energy requirement for operations is achieved by very simple means; thick insulation, air tightness and efficient air-heat exchanger, and could therefore be applied to any residential building. The row houses had solar collectors on the roof for hot water production.

Table 1. The studied buildings. The calculated energy need includes energy for heating, electricity and hot water.

	Stories	Type	Apartments	Main material	kWh/m^2	Energy source
Lindås	2	row-house	20 in 4 rows	wood	45 1)	100 % electricity
Karlstad	12	tower block	44	concrete, wood	50	63 % electricity and 37% district heating
Värnamo	2	row-house	8	concrete, wood	67	100 % electricity

1) Measured energy need was 68 kWh/m^2 (Karlsson 2004).

In the presented study, the measured value for operation for the Lindås building was used.

4 METHOD

The processes included in the life cycle were; production of building materials, transport to the building site, waste, maintenance, and operation. Energy for erection and demolition was not included. Materials such as adhesives, seals, nails and screws and a few minor components were not included.

The lifetime was assumed to be 50 years. Maintenance intervals were based on the maintenance code of municipal housing companies.

Several re-designs were studied in order to minimize or maximize the embodied energy. Heating energy was calculated for the original construction by using a dynamic calculation method. The U-values were not changed in the re-designs. The changes in heat storage, due to material changes made in the re-designs, were assumed to be of insignificant importance to the operation [Hagentoft 2000].

Recycling was subdivided into reuse, material recycling, and combustion with energy recovery. The three forms were defined as follows: Reuse: The material is used for about the same purpose as initially. For example, a clay brick is reused as a clay brick. Reuse might imply upgrading or some renovation. Material recycling: Only closed-loop recycling was assumed. However, crushed concrete and clay brick were assumed as coarse aggregate in roads as a substitute for gravel. Combustion: Combustion with energy recovery. It should be pointed out that the forms of recycling and the recycling rates do not represent the general practice of Swedish recycling of today, but all techniques have been practised with good result.

The recycling potential, Rpot, express how much of all embodied energy and natural resources used in a building or a building element could, through recycling, be made usable after demolition. The Rpot for a building was calculated as

$$R_{pot} = \sum_{i=1}^{n} EE_i * \text{Remaining lifetime}_i - E\ rec.proc_i \qquad (1)$$

where where EE is the embodied energy of the material for which the recycled product will be a substitute; i is the material number; and n is the total number of materials. Remaining lifetime is the remaining lifetime of the recycled material, given as a percentage of the predicted lifetime of the material for which the recycled material will be a substitute. E rec:proc is the energy used for all recycling and upgrading processes, including additional energy use that will be needed for the disassembly in order to make future recycling or re-use possible; this also includes the transport of recycled materials.

Energy use for production and assumed energy savings for respective material are presented in [Thormark 2001].

The recycling potential was calculated for two scenarios: (A) maximum material recycling/combustion with heat recovery, and (B) maximum re-use. Each component and its integral material part(s) were assessed for the possibility of reuse/recycling. In Scenario A, a maximum rate for material recycling or combustion was applied. All materials possible to sort after deconstruction were assumed to be recycled. In order to define the possible sorting rate for each material, several deconstruction, sorting and recycling companies in Sweden were interviewed. In Scenario B, a maximum rate of re-use was applied. Sorted materials not suitable for re-use were assumed to go for material recycling or combustion.

In buildings without heating system, the aim is that the building is so energy efficient, so well insulated, that no heating system is needed [Sandberg 2003]. The heat losses through the insulated shell and the ventilation are during a major part of the year, compensated by heat from activities and people in the building. This means that the major part of the energy need for operation is from electricity. In Lindås and Värnamo, all energy for operation is electricity while Karlstad uses 63 % electricity and 37 % district heat.

Four different ways of electricity production was used; Nordic electricity mix, EU25members mix, electricity produced in Swedish thermal power plant and electricity produced in Danish thermal power plants.

The environmental impact was studied for global warming, acidification, eutrophication, photochemical ozone and use of resources.

5 RESULTS

5.1 *Energy and recycling potential*

The energy need for production and the recycling potential are presented in Table 2. In the scenario 1 (material recycling/combustion), the recycling potential varied between 27-34 % of the energy for the material part. In the scenario 2 (reuse), the result was 30-38 %.

In a comparison of two buildings regarding primary energy, identical in construction and insulation standard but with different energy suppliers, the results may vary significantly. One method to compare buildings without letting the supply of energy influence the results, is to express energy for operation as bought energy. This method was used by Adalberth and the material part in Swedish dwellings from the 1990s was about 15 % [Adalberth 1997]. When this method was applied in the present studies, the material part accounted for 37-38 % of the total energy need over 50 years.

Table 2. Energy for production and the recycling potential in scenario 1 and 2. (MJ primary energy/m^2 floor area).

	Material new build.	Wastage	Maintenance	Feedstock	Transports	Rpot scen 1	Rpot scen 2
Lindås	2755	598	1096	2602	206	2474	2827
Karlstad	3228	159	787	865	331	1490	2046
Värnamo	4760 (material new build., wastage, maintenance)			2332	224	2015	2252

In Table 2, the high energy need for maintenance should be noticed. The figures correspond well with results found by Adalberth [Adalberth 1997].

5.2 *Environmental impacts*

The environmental impact was studied for global warming, acidification, eutrophication and photochemical ozone creation. For the operation, all energy need was assumed to be electricity and four different ways was used to produce it; Nordic electricity mix, EU25members mix, electricity produced in a Swedish heat power plant and a Danish heat power plant. Results are presented in Table 3.

Table 3. The span between the three buildings regarding impacts from the material part as % of total impact (material part + operation). Four ways of electricity production was used for the operation.

	Nordic electricity mix	EU25 electricity mix	Swedish TP[1)]-plant electricity, heat	Danish TP[1)]-plant electricity, heat
GWP 100	45-65	24-45	20-36	16-31
Acidification	53-73	28-51	33-52	14-29
Eutrophication	44-65	27-48	35-53	15-30
Photochemical ozone	53-70	26-47	55-74	19-37

[1)] TP-plant is electricity and heat generation in thermal power plant.

The use of resources for energy production was assessed with four assessment methods; EPS 2000 V2.1, EcoIndicator99 (hierachist perspective), CML 2 baseline 2000 and EDIP. (EPS 2000 [Steen 1999], EcoIndicator 99 [Goedkoop 2001], CML 2 baseline 2000 [Guinée 2002] and EDIP [Wenzel 1997]).

Table 4. The span between the three buildings when four assessment methods were used to assess the use of resources for energy production for the material part as % of the total use of resources for energy production (material part + operation). Four ways of electricity production was used for the operation energy.

	Nordic electricity mix	EU25 electricity mix	Swedish TP-plant[1)] electricity production	Danish TP-plant[1)] electricity production
EPS 2000	50-61	29-32	12-17	8-12
CML 2000	46-59	31-43	42-55	5-8
EDIP	53-63	30-39	40-50	7-9
EciIndicator99	66-75	24-32	37-47	10-14

[1)] TP-plant is electricity and heat generation in thermal power plant.

5.3 *Effects of material substitution*

For each building materials were substituted to achieve a maximum and a minimum version regarding energy use for the material part. Sometimes additional materials had to be added in order to fulfil technical requirements and to retain the insulation standard. The performed substitutions are presented in Table 5. In each building the maximum version was about 15-20 % higher than the minimum version.

Except for the effect on resources for energy production, the choice of material also affected the use of resources in the building materials. In Karlstad the difference between the Minimum and Maximum case regarding use of coal was 49%, iron ore 56%, oil 75% and gas 90%.

Table 5. Energy for production and the recycling potential in scenario 1 and 2. (MJ primary energy/m^2 floor area).

	Original material	Minimum	Maximum
Foundation	EPS	Perlite	as original
Lindås			
External wall			
Lindås	glass wool, EPS	celluloose fibre, glass wool	as original
	wood studs s 450 mm	wood studs s 600 mm	
Karlstad	steel studs, wood studs	wood studs	as original
Värnamo	wood studs	manufactured wood studs	steel studs
	glass wool	celluloose fibre, glass wool	as original
Internal wall	steel studs, s 450 mm	wood studs[1)], s 600 mm	as original
all			
Wall between flats			
Lindås	wood studs, s 450 mm	wood studs, s 600 mm	steel studs, s 450 mm
Karlstad, Värnamo	concrete	massive wood	as original
Floor structure			
Karlstad, Värnamo	concrete	massive wood	as original
Roof			
Lindås	clay brick tiles	green roof covering	aluminium sheet
Värnamo	concrete tiles	green roof covering	as original
Surface materials			
Karlstad, Värnamo	clinker (hall, bathroom)	as original	PVC (hall, bathroom)

1) steel studs in bath room

6 DISCUSSION

6.1 *Discussion of the results*

The material part accounted for about 35 % of the total energy use and this figure corresponds very well with the findings by Kohler (Kohler 2004).

The material's part of the total environmental impact is of course very much related to the energy mix for operation. The material's part of the total impact increases with 'cleaner' mix for operation. The European mix is probably rather similar to the mix used by Kohler and the result for the European mix corresponds well with Kohler's result. The difference between the energy use and the environmental impact clearly shows the importance not to limit the studies to only energy use; environmental impacts must be included.

The result also shows that, especially for low energy buildings, it is very important not to attach the prevailing picture that 'operation accounts for the main part'.

In conventional buildings, the main issue for improvement is the energy need for operation. In addition the choice of source of operation energy (when it is possible to choose) is an important issue for the building users of both conventional and low energy buildings.

However, in low energy buildings, the choice of material seams to be as important as the operation energy and more attention ought to be paid to the choice of building material. Several reasons suggest this. One reason is that the choice of building material may affect the energy need for the material part about 15-20 %.

Another reason to pay more attention to the choice of building materials is the use of resources. The study on the use of recourses was limited to the resources used for the energy production. However, the use of recourses is not only affected by the energy mixes and how much energy is used for the material production. It is even more affected by the resources in the materials and by that, the choice of building materials. In the Karlstad case, the difference between the cases regarding use of resources was for example 49% for coal, 56% for iron ore, 75% for oil, clean 90% for natural gas (Thormark 2006).

A third reason is the recycling potential. The recycling potential is not at all related to the energy use for production. For example, mineral wool insulation requires quite a lot of energy to produce but the energy saving by material recycling is small. Mineral wool can be reused but this requires that the construction is suitable for disassembly and that the wool has not been decontaminated during use. It requires attention to the material choice to produce buildings with both low energy need of the production and a high recycling potential,

Transports are in earlier studies of buildings in a life cycle perspective, said to be of minor, insignificant importance. However, here transports accounted for more than a 1/3 of the total photochemical creation, irrespective of the energy source for operation. Therefore, transport distances should not be neglected.

More studies are desirable on how the choice of material can decrease the environmental impacts.

Low energy buildings differ from conventional buildings in three ways. They use more material, less energy for operation and they use electricity for all operation. Energy for material production is in general causing more environmental impacts than electrical energy production and considerably more impacts than district heating. Therefore, a question is whether low energy buildings or conventional buildings heated with district heat will cause the most environmental impact. This is studied in an ongoing study. It can be assumed that the choice of building material will be of considerably more importance than previously expected.

6.2 *Discussion of the data*

Several conditions may influence the results. One is the data quality for the building materials. The results from the substitution of materials in the studied cases are judged to be of minor significance.

Regarding the environmental impacts from electricity, the impacts from the nuclear power is difficult to handle. In the EU25 electricity mix there is as much as 31 % nuclear power (in the Nordic 26 %) but in the material part only about 4 %. The global warming, acidification etc have to be weighed against the risks of radiation. In the assessment of resources, uranium is included only in two of the used methods; the EPS and CML method.

If the energy sources for material production will change drastically in the future, this is likely to affect the results. Figure 1 shows emissions of carbon dioxide from some processes. The carbon dioxide from residential and services are due to an extended use of district heating for heating. The carbon dioxide from industrial production in Sweden, however, has not decreased, rather increased, during the period. Even with new goals to reduce the emissions of carbon dioxide, it can be assumed that no drastic change will occur in the near future.

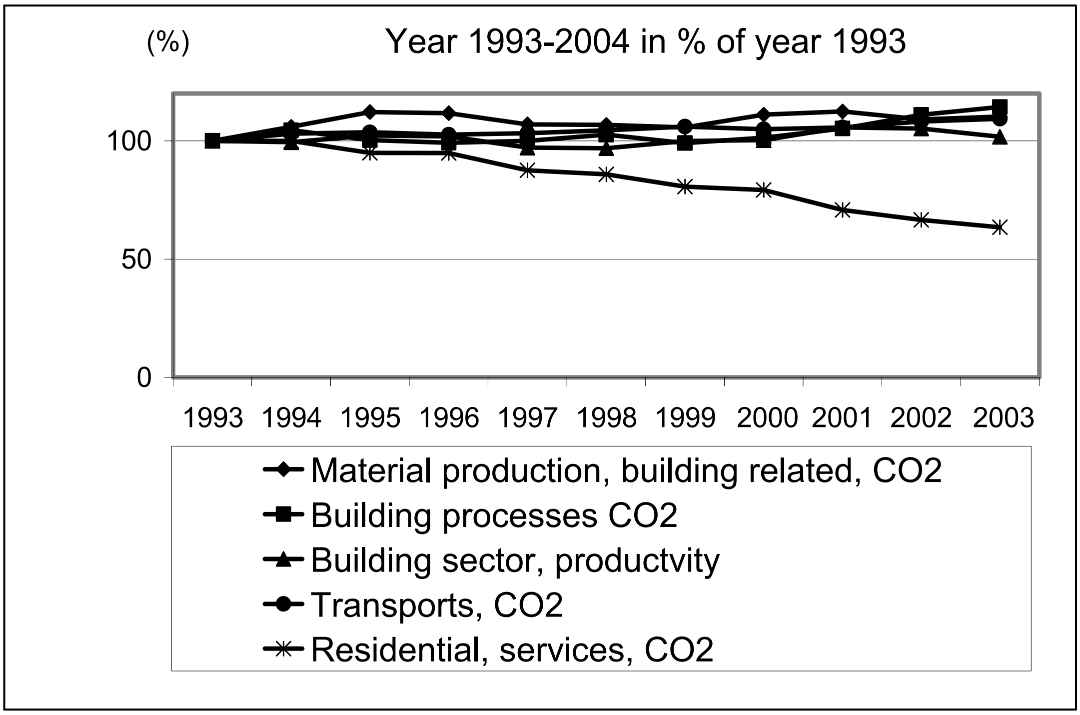

Figure 1. Emissions of carbon dioxide and building production in Sweden 1993-2003. (SCBb).

7 CONCLUSIONS AND RECOMMENDATIONS

In the design of new buildings, it is not only important to decrease the energy need for operation. The energy source for heating, the choice of building materials and the aspects of reuse/material recycling is also of great importance. In order to increase both the condition and the benefits from reuse/recycling, it is important to design for disassembly.

In the material part, maintenance often accounts for a considerable share. Therefore, prolonging the lifetime of materials/components with short maintenance interval and using materials/components with low environmental impacts can greatly reduce the impact from maintenance.

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REFERENCES

Adalberth K. (1997). Energy use during the life cycle of single-unit dwellings: examples. Building and Environment 1997;32:321–9.

Buchanan A, Levine B. (1999). Wood-based building materials and atmospheric carbon emissions. *Environmental Science & Policy* 1999;2:427–37.

Feist W. Life-cycle energy balances compared: Low-energy house, passive house, self-su1cient house. Proceedings of the International Symposium of CIB W67, Vienna, Austria, 1996. p. 183–190.
Gao W, et al. (2001). Energy impacts of recycling disassembly material in residential buildings. Energy and Buildings 2001;33:553–62.
Goedkoop, M. Et al. (2001). The Eco-indicator 99. A damage oriented method for Life Cycle Impact Assessment. Pre Consultants B.V. Amersfort, Holland.
Goverse, T. et al. (2001). Wood innovation in the residential construction sector; opportunities and constraints resources. Conservation and Recycling 2001;34:53–74.
Guinée, Jeroen B. (Ed.) (2002). Handbook on Life Cycle Assessment Operational Guide to the ISO Standards. Springer förlag. ISBN: 1-4020-0557-1.
Hagentoft C-E, Svensson C. (2000). Energieffektivt och god termisk komfort genom va¨ rmelagring i byggnaden. Bygg &teknik 5/2000. Stockholm, Sweden: Förlags AB Bygg & Teknik; 2000.
Karlsson, F. (2004). *Varaktighetsdiagram för "Hus utan värmesystem".* Report LiTH-IKP-R-1342. Energi Systems, Linköping university.
Kohler, N. et al. (2004). *Low emission buildings (LEB). Institut für Industrielle Bauproduktion, Universität Karlsruhe.*
Nielsen, P. et al. (1995). Energi- og miljöanalyser af bygninger. (In Danish) Energy- and environmental analysis of buildings) SBI-medelelse 108. Danish Building Research Institute, Hörsholm, Denmark.
Petersen A, Solberg B. (2005). Greenhouse gas emissions, life-cycle inventory and cost-ef.ciency of using laminated wood instead of steel construction. *Environmental Science & Policy* 2002;5: 169–82.
Projektet för passivhus. (2006). Marknadsöversikt för passivhus och lågenergihus i Sverige. Projektet för passivhus; Göteborg.
SCB a), Statistics Sweden; Final energy use within the residential and service sectors etc, 1970–2005, TWh.
SCB b), Statistics Sweden; Emission of carbon dioxide (CO2) in Sweden 1980 and 1990–2004. and Statistics National Institute of Economic Research; Swedish Economy/Output and Labourmarket/Productivity.
Sandberg, E. (2003). *Hus utan värmesystem*. ATON TeknikKonsult ab. www.aton.se.
Scheuer C, Keoleian GA, Reppe P. (2003). Life cycle energy and environmental performance of a new university building. *International Journal for Energy and Buildings* 2003.
Steen, B. (1999). A systematic approach to environmental strategies in product development (EPS). Version 2000 – Aodels and data of the default methods. Centre for Environmental Assessment of Products and Material Systems. Chalmers University of Technology, Technical Environmental Planning, CPM report 1999:5.
Thormark, C. (2001). Conservation of energy and natural resources by recycling building waste. Case study. *International Journal of Conservation, Resources and Recycling,* Vol 33/2, pp 113-130.
Thormark, C. (2006). *Energi- och resursanvändning i ett 12-vånings lågenergihus utan Värmesystem. Kv Seglet 1, Karlstad*. Report ISRNLUTVDG/TVBP--06/3089—SE. Lund Institute of Technology, Dep. Of Construction Management.
Wenzel, H. et al. (1997). Environmental Assessment of Products. Del 1. London: Chapman & Hall.
Winter, B, N., Hestnes, A.G. (1999). Solar versus green: The analysis of a Norwegian row house. *Solar Energy*, Vol. 66, No. 6, 1999, pp 387-393.

Construction and demolition waste management in Portugal

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ABSTRACT: Recycling in Portugal is a fairly new business, especially when it comes to construction and demolition waste (CDW), where recycling efforts are minimal, although gaining momentum. Efforts to determine the quantity of nationally produced CDW have resulted in huge discrepancies, which highlight the necessity to further persue a more precise account of this generation. Nevertheless, a few recycling facilities have started working in some regions, even without specific legislation concerning CDW recycling, which means that there is a great profit potential for this industry. Although the output material is not of great quality (aggregate mix with several contaminants), it can be used in applications as secondary road base or undemanding building groundfloors. The legislation frame related to CDW is almost non-existant although seen as crucial to a proper development of the CDW recycling business.

1 INTRODUCTION

The construction industry in Portugal does not have a tradition in re-using or recycling wastes which are generated in construction and demolition activities. While other industries have started collecting and recycling their products, as plastic and paper industries, mainly due to stricter environmental legislation referring to Municipal Solid Waste (Portugal has only recently finished banning open-air dumps), construction and demolition companies are still allowed to dump their waste in landfills, when not illegally at the road-side (Fig. 1). Although mainly inert, CDW amounts to enormous quantities and, if not recycled or re-used in some way, contributes to the ongoing depletion of natural resources (stone, sand, oil (plastics), wood) and exhausting of landfill space. Just as a reference, Municipal Solid Waste (MSW) generation in Portugal amounts to about 4.550.000 ton/year (derived from Waste Institute information), while CDW production rises up to 6.440.000 ton/year (a national projection of the amount presented in (Pereira 2002)). This means that, at least in terms of quantity, CDW is a greater problem, in Portugal, than MSW.

Although the overall picture is not bright, efforts have been undertaken in favour of recycling CDW, as seen from the work of starting recycling plants in several parts of the country. These facilities basically collect non-dangerous mixed CDW (collecting different fees at the entrance, depending on the waste mix level and its density), separate it mainly by hand labour and crush into several grain sizes the resulting material. Although this output product is of low quality, most materials that enter the facility are actually sent to be recycled (paper, cardboard, wood, plastics (some varieties), metals, glass), after receiving companies (legally operating recyclers, as listed in (National Directory of Environment and Natural Resources 2006)) have been contacted and established which quality condition applies for each material to be recycled.

Figure 1. Abandoned CDW at a road-side near Lisboa

This paper aims to give an overview, as accurate as possible, of the CDW recycling activities in Portugal, in order to expose the existent barriers but also to identify the opportunities that lay on its path. A short insight on recent attempts to quantify CDW generation, followed by a description of two recycling facilities and their working process, an overview on some CDW management operations in several parts of the country and comments on the Portuguese legislative frame concerning CDW management constitute the main chapters which this paper is composed of.

2 QUANTIFICATION OF CDW GENERATION

Although some attempts have been made to quantify CDW in Portugal, variations are too great to reach any conclusive figure. Consulted studies present values are as different as 235.774 ton/year (Salinas 2002), 7.691 ton/year (Carvalho 2001) and 2.132.600 ton/year (Pereira 2002), the latter only for the Portuguese northern region. European estimations have attributed to Portugal about 3.200.000 ton/year, calculated from a CDW capitation of 325 kg/person/year, with a 9,9 million population (Symonds Group Ltd., 1999). Other estimates have resulted in 95 kg/person/year (CDW without soil content) and 190 kg/person/year (CDW with soil content), reported has having been deposited in legalized sites (FCT Project POCTI / ECM / 43057 / 2001, 2004). From the referred figures, the one presented in (Pereira 2002) is considered by the authors, up to this moment, as the most realistic number, since it actually relied on a systematic direct and indirect contact survey of private and public institutions, namely through personal interviews, email enquiries and telephone contacts.

There are several reasons that account for such differences in the presented numbers. One is the generalized ignorance, as far as CDW is concerned, from producers, transporters to municipalities, which tend not to keep records of quantities produced, transported, landfilled, recycled or reused, although this procedure is a part of the Portuguese law, concerning these matters (see chapter 5). Another reason is the illegal discharging that is still occurring by all agents, namely contractors, transporters and municipalities as well, although there are already a few legalized industrial inert waste landfills in the country (DECRETO-LEI n.º 152/2002), which remain, however, underused (Jornal de Notícias, in press, 2006). Other reasons might be related with what is considered CDW, since, for example, soils constitute a large share of the average composition of CDW if included, although not quite representing a waste (recent legislative efforts have already acknowledged this fact, see chapter 5), since it is not a transformed material (contaminated soils, however, are rightly labelled as waste, which must be treated in order to return to the natural environment).

Other attempts to quantify CDW generation, as already in progress by the authors, follow the same logic as in (Pereira, 2002), aiming at the collection of as much *in situ* information as possible (mainly from construction and demolition contractors and CDW recyclers), not only on global CDW amounts but also on specific waste flows (concrete, masonry, wood, plastic, metals and so on) and trying to associate these with their origin (residential, non-residential and from construction, renovation and demolition activities).

3 EXISTING RECYCLING PLANTS

3.1 *Description and location*

Up to this date there is only one recycling plant working on CDW, already active (since beginning of 2006). This plant is owned by TRIANOVO, located in Torres Vedras (TRIANOVO recycling plant – Location: Casais da Serra, 2560-057 A-dos-Cunhados, Portugal). Another one, inaugurated in April 2007, is called ECOLABOR (http://ecolabor.paginas.sapo.pt/ (in Portuguese)) and will receive CDW from Sintra region, although it is still not fully active.

TRIANOVO is a basic collecting, separating and crushing plant, which sells separated materials to other recyclers (plastics, wood, paper, metal, glass) and supplies graded fill aggregate, mainly composed by crushed concrete, brick and mixed fines. Mixed CDW are deposited in a central area where large pieces of contaminants are first separated and oversized concrete blocks are reduced to fit in the crusher input opening. Then materials are transported up the separating belt (Figure 2), which runs at an average speed of 0,2m/s, where medium size contaminants are separated by hand by one worker per separate fraction. The resulting aggregate fraction is then conducted to the crusher belt, passing through an overhead magnet, which picks up medium sized ferrous metals. The crusher plant has three separate crushers, tuned to deliver several aggregate sizes. The plant receives around 250ton/day of CDW, half of which is composed by mixed soils.

ECOLABOR (Figure 3), although not processing CDW until very recently, is equipped with an air blower (to separate the light materials from the heavy aggregates), a jig table (to isolate different grain sizes) and a portable fine separator (mounted on an excavator). This equipment will speed up the separating process, while enhancing the output materials quality.

3.2 *Input materials*

Generally, input materials are all mixed, which of course results in a more expensive separation process and lower final product quality. However, the recycling plant guarantees profitability by charging accordingly to the input mix level, using the values stated in Table 1 (which may vary). For contaminated mixed aggregated, which belongs to a certain category between

Figure 2. Separating belt feed at TRIANOVO recycling plant

Figure 3. General view of ECOLABOR recycling plant

Table 1. Prices charged for incoming materials at TRIANOVO recycling plant

CDW type		Price charged, €/ton
Soils		1
Clean mixed aggregates		2
Contaminated mixed aggregates	only with high density wood and/or ferrous metals	4
	with any kind of low density non hazardous contaminants	60

high density wood and ferrous metal contaminants and any kind of low density non hazardous contaminants (as for instance plaster/plasterboard and low density wood), a price between 4 and 60€/ton is charged. The great difference in prices has to do with the level of contamination, which is associated with waste density, or in other words, the less dense the mix waste is, the more likely it is to be harder to separate and the lower quality it will have as an output material, which will result in financial losses for the recycler. This way the recycler defends itself from higher treating costs and at the same time encourages source separation.

The plant accepts all aggregate materials containing concrete, bricks, tiles, rock and soils, which all together build up to over 99% of the input weight (Mimoso 2006). Mixed with the aggregates are also plastics, wood chips, paper, glass, ferrous metals, non-ferrous metals and other contaminants (such as gypsum), which represent only about 0,5% of the total weight (Mimoso 2006). 0,03% corresponds to the rejected materials (for instance, certain kinds of plastic that are not accepted by local recyclers), which cannot be sent to other recyclers and are unsuitable to remain in the aggregate fraction. This last fraction is sent to a controlled landfill. Bituminous concrete is accepted under strict conditions, although presently it is not being recycled. Hazardous materials are generally not accepted, which means the central rejects the discharge if these materials are detected (for instance asbestos, tar, paints, industrial oils and contaminated soils). This means that the producers of hazardous waste must separate them at the source and transport them to specialized recyclers, not to common CDW recycling plants.

Recycling initiatives in other parts of the country will most probably receive similar input products, which may vary depending on the demolition works taking place at that region (buildings age being demolished) and any source separation initiative (which is, however, unlikely).

3.3 *Output products*

Combining highly mixed input materials with lack of machinery to completely separate them, especially the fine fraction, output quality is not high. Therefore, the output aggregate can only be used for unspecific fills. Furthermore, there is no quality control over the final product, which also results from insipient national regulation on recycled construction products (although there are already four LNEC standards, see Chapter 4).

It is clear, however, that producing output products to be used in concrete or in top road layers (bituminous concrete), over which recent standards focus, is out of reach for the kind of recycling facilities emerging nowadays in Portugal. The industrial process to obtain such high quality materials (that may compete on a technical basis – let alone economical - with virgin materials) is much more complex, expensive and relies on strict quality control procedures (Xing 2004). These conditions and the lack of acceptance of recycled materials by both the Portuguese road construction and concrete industry, makes it almost impossible that such an initiative takes place today.

This high recycling level, as a matter of fact, has not been common, not even in the most developed countries (examples: Netherlands, Germany, United Kingdom, Denmark), in what concerns CDW management, due to the still large market for using recycled aggregates in road construction (especially in base and sub-base layers), which results in low recycled aggregate usage in concrete production.

3.4 *Management options*

In spite of low CDW recycling tradition in Portugal, some experiments have already been conducted, from which a few management options can be derived.

In the demolition of three concrete structures in the north of the country (in 2004) – south part of Boavista football stadium, FC Porto stadium and a factory (Hipólito et al. 2004) – ferment factory in Matosinhos – basic demolition, separation and crushing techniques were used in order to recycle the majority of the demolished materials. In each of these three cases, source separation was conducted, removing non-structural materials as plastic, wood and metals, pilling them separately and sending them to independent recyclers. This was done rather easily because these are relatively uncladded structures, which means there were few finishing layers and small amounts of other materials such as cables, isolation, window frames and floor coverings (when compared to the global amount of concrete). As a result, concrete demolition was conducted on rather stripped structures, which allowed crushing clean concrete rubble (with a mobile crusher/screener), after taking out the reinforcement with hydraulic scissors. Still, the resulting recycled aggregates were not used for new concrete production, being used, instead, in low grade pavement fills.

Another case study was reported, in 2001, for the José de Alvalade stadium, in Lisbon, were selective demolition was performed on all concrete support structures. Demolition, separation and crushing techniques were similar to those cited above. However, a more in-depth study was conducted, in order to determine the technical feasibility of using the recycled aggregates in new concrete (dos Santos et al. 2004). The results were rather promising, with 100% recycled aggregate concrete showing good mechanical properties (compressive strength, flexural strength and modulus of elasticity) when compared with natural aggregate concrete, although demanding somewhat a greater amount of mixing water, mainly due to the higher recycled aggregate water absorption.

Still another case, presently ongoing, accounts for the (partial) selective demolition of Estoril-Sol Hotel, in Estoril, Portugal (Figs 4-5). This reinforced concrete building constructed in the 1960's has been targeted to demolition as it no longer serves the modern functional and financial purposes of its owners. The demolition bid, however, has been won by Ambigroup, a Portuguese group of companies dedicated to waste management, developing in recent years capabilities in large CDW management operations, namely in technical and logistic aspects.

This specific case has involved locating, separating and sending to treatment facilities (which may not recycle these materials, but only landfill them in a controlled way) of hazardous materials as asbestos and mineral oils; selective removal of carpets, wood frames, glass, doors, metal frames, sanitary, electrical cables and insulating materials; unselective demolition of remnant materials – reinforced concrete, masonry, tiles, plastic pipes and gypsum boards and source separation of all valuable metallic materials (reinforcement and steel joists and plates). All metals were sent for recycling, as well as glass, since there is a well established market for recycling these materials. Combustible materials as wood doors, carpets, wood frames and cables have been incinerated at Secil-Outão cement factory, as alternative fuel. Finally, all other materials (over 90%, in weight, of all materials taken from the building), which had lime and silica content (concrete, masonry and tiles), were sent to the main clinker burner at the same mentioned cement factory. Overall, although the actual recycled material percentage was low, in total weight, dumping was avoided in almost every material fraction, allowing instead for energy recovery (alternative fuels) and secondary raw material use (ceramic minerals for clinker production).

Figure 4. Concrete, masonry and ceramic materials after demolition and size reduction, at Estoril-Sol working site

Figure 5. Reinforcement steel and other metals separated for recycling, at Estoril-Sol working site

As far as CDW management options are concerned, the Portuguese situation is not much different from those encountered in other countries, which means there is great recycling potential, even with basic equipment and mainly low-grade recycling applications.

4 PORTUGUESE LEGISLATION FRAME CONCERNING CDW

The Portuguese legislation frame concerning CDW has been developing, especially in recent years. In Table 2, an overview of these documents is presented, in chronological order.

Table 2. Main legislative documents, which may concern CDW, released in Portugal, in recent years

Legislation reference	General description
Portaria nº 15/96, 23rd of January, 1996	Approves waste management operations
Portaria nº 335/97, 16th of May, 1997	Establishes rules for waste transportation
Portaria nº 818/97, 5th of September, 1997	Approves the European list of wastes (all kinds)
Decreto-Lei nº 239/97, 9th of September, 1997	Establishes general rules for waste management
Portaria nº 961/98, 10th of November, 1998	Legislates authorization processes in managing industrial, urban and other kinds of waste
Portaria nº792/98, 22nd of September, 1998	Approves the non-hazardous industrial waste map
Decreto-Lei nº 321/99, 11th of August, 1999	Regulates the installation and management of non-hazardous industrial landfills
Decreto-Lei nº 516/99, 2nd of August, 1999	Approves the Strategic Plan for non-hazardous industrial waste
Decreto-Lei n.º 152/2002, 23rd of May, 2002	Regulates the installation, use, closure and post-closure procedures for landfills
Portaria nº209/2004, 3rd of March, 2004	European waste classification list
Decreto-Lei nº 178/2006, 5th of September, 2006	Establishes general rules for waste management. Replaces Decreto-Lei nº 239/97

In spite of all the waste management legislative effort undergone since 1996 (even though the first published law over waste management, in Portugal, goes back to 1985, with DECRETO-LEI nº 488/85), there has not been published, up to this moment, a specific law concerning CDW management. However, a draft legislative document is under preparation since 2005, to address this specific waste management issue. This document calls for certain definitions and actions/management options, which can be summarized as follows:

- Non-contaminated soils are excluded from the CDW stream - an important issue, since soil can take up a considerable percentage of total CDW waste, if considered. This is based on the average Soil/Total CDW relationship calculated for several European countries (values presented in (Pereira, 2002)), which is around 60%;

- Focuses on reduction as the basis of CDW management, with reuse and recycling as the preferred options, after generation;
- Defines the responsibility chain, in CDW production and management;
- Calls for previous CDW generation study for each construction project, which must always be a part of the bid process, stating the Owner as its responsible;
- Obliges the Owner to pay previously to the municipality a certain amount (3 or 10% of the contract amount, depending if this contract involves only construction/retrofit or only demolition) to guarantee CDW management in case of improper or inexistent plan of action;
- Non-compliance with its basic principles involves payment of fines and/or losing the right to exert (construction or demolition) activity.

In order to positively influence sound CDW management, this legislative draft also defines incentives, to be applied during the bid processes, which shall incorporate CDW management good practices as one of the decision parameters (in winning or losing a bid).

It is also worth mentioning that the National Civil Engineering Laboratory (Laboratório Nacional de Engenharia Civil – LNEC) has recently produced four recycling standards, one for structural concrete – Guide for the use of recycled coarse aggregates in concrete, E469-2006; another for bituminous concrete – Guide for the production of recycled hot mix asphalt, E472-2006, a third one for pavement layers – Guide for the use of recycled aggregates in unbound pavement layers, E473-2006; and, finally, the last one for embankments and capping layers – Guide for the use of construction and demolition recycled materials in embankments and capping layers, E474-2006. Although the relevance of such standards is undeniable, if high level recycling is to be done in the Portuguese construction industry, there is, at the moment, little possibility in doing so, due to lack of advanced CDW recycling technology and source separation actions (which render high level recycled output construction products – as structural concrete or bituminous top layer concrete - uneconomical).

5 CONCLUSIONS

A general presentation of the CDW management situation in Portugal has been reported in this paper. Although still insipient, a CDW market is developing, along with shortage of dumping sites, higher tipping fees and longer distances to legalized landfills. Effort has been applied in developing legislation concerning waste production, transport and treatment in Portugal, although a dedicated CDW standard is still unpublished.

However, even lacking specific legislation, some industrial initiatives have been started (TRIANOVO, ECOLABOR) and a few companies (AmbiGroup) have been investing in logistics and machinery for conducting selective demolitions (dismantling), while setting up commercial networks between transporters, recyclers and cement factories (in the cited example, Secil-Outão). These initiatives show that there is a high lucrative potential in CDW recycling activities, since generated quantities are very significant, a recycling market already exists for some important CDW fractions – steel/metals, wood, plastics and paper – and there is a high demand for unspecific filling materials, base foundation layers and road bases and sub-bases.

Although the general quality of CDW recycled output materials is low, mainly due to highly mixed input flow, low tech recycling equipment, lack of quality control and non-existent demand for recycled high-value products (such as recycled structural concrete or bituminous concrete), the developing of new recycled material standards (for instance, LNEC E469-2006, E472-2006, E473-2006 and E474-2006) and specific legislation under preparation will certainly create better conditions to backup recyclers, incentive producers to reduce and manage their CDW and help clients to better understand and learn to trust recycled materials.

6 FUTURE RESEARCH

More accurate and categorized CDW quantification is needed in Portugal. Therefore, a case-driven data gathering initiative is crucial, in order to give recycling investors, clients, contractors and designers previous knowledge of the generated quantities per type of building and/or predictions per material flow, which allows them to take management decisions and allocate funds.

Thorough information gathering on CDW recycling technology is also needed, in order to organize in a systematic way all the technological possibilities in mobile and fixed recycling operations, for different material inputs and desired output quality. A complete study on selective demolition is also important, to allow a direct comparison in material and financial terms between selective and traditional demolition practice.

Finally, a profound operational and economical analysis of a fixed recycling industrial facility is of great importance, since this can help to better understand the complexities of the CDW recycling industrial system, its optimization and ways to render it as lucrative as possible. This also generates background knowledge for future CDW recycling investors, helping them to overcome some market barriers and explore current possibilities.

7 ACKNOLEDGMENTS

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REFERENCES

Carvalho, Pedro L. G., 2001. *Managing Construction Industry Waste*. Masters Thesis, Instituto Superior Técnico, Technical University of Lisboa (in portuguese)

DECRETO-LEI n.º 152/2002. *Licenced landfill sites in Portugal*. (in Portuguese)

dos Santos, José Roberto et al. 2004. Mechanical properties of concrete with coarse recycled aggregates – study for the demolition of a stadium. *Structural Engineering International*, V. 14, n.º 3, International Association for Bridge and Structural Engineering: 213-215

E 469 – 2006, Guide for the use of recycled coarse aggregates in concrete, National Civil Engineering Laboratory (Laboratório Nacional de Engenharia Civil – LNEC), March 2006 (in Portuguese)

E 472 – 2006, Guide for the production of recycled hot mix asphalt, National Civil Engineering Laboratory (Laboratório Nacional de Engenharia Civil – LNEC), May 2006 (in Portuguese)

E 473 – 2006, Guide for the production of recycled aggregates in unbound pavement layers, National Civil Engineering Laboratory (Laboratório Nacional de Engenharia Civil – LNEC), May 2006 (in Portuguese)

E 474 – 2006, Guide for the production of construction and demolition recycled materials in embankments and capping layers, National Civil Engineering Laboratory (Laboratório Nacional de Engenharia Civil – LNEC), May 2006 (in Portuguese)

FCT Project (POCTI / ECM / 43057 / 2001), 2004. *Integrated CDW management*. Technical University of Lisbon, Technical Institute of Lisbon and Engineering University of Porto, Report (in Portuguese)

Jornal de Notícias, press edition on 25.09.2006 – available on
http://jn.sapo.pt/2006/09/25/centro/ha_inertes_todo_o_lado_aterro_contin.html (in Portuguese)

Lilibeth, A. Salinas, 2002. *Managing construction and demolition waste, a contribution for the municipal construction waste management*. Masters Thesis, University of Coimbra (in portuguese)

Mimoso, Pedro, 2006. *Construction and demolition waste management*, Presentation in Vila Real, Portugal

National Directory of Environment and Natural Resources, 2006 – 5.40 Salvaging, recycling and reusing, website: http://www.markelink.com/directorios/Amb2006/titulos/5.040.htm (in Portuguese)

Pereira, Luís C. H., 2002. *Construction and demolition waste recycling: the case of the Portuguese northern region*. Masters Thesis, University of Minho (in Portuguese)

Sousa, Hipólito et al. 2004. Demolition of some structures and sustainability. Some case studies, *Congress Construção 2004: Repensar a Construção,* Porto: Porto Engineering University (in Portuguese)

Symonds Group Ltd, 1999. *Construction and Demolition Waste management practices and their economic impacts*. Report to DGXI, European Commission –46967 Final Report

Waste Institute, website: http://www.inresiduos.pt (in Portuguese)

Xing, Weihong, 2004. *Quality Improvement of Granular Secondary Raw Building Materials by Separation and Cleansing Techniques*, Delft: Delft University of Technology.

Lime-metakaolin mortars – properties and applications

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ABSTRACT: Lime is the most sustainable binder due to lower production energy needs, lower CO_2 emission during production and CO_2 absorption by carbonation. For centuries it was used in both mortars and concretes until it was replaced by Portland cement, due to faster hardening, higher strength and apparent longevity. However, in building conservation actions, the use of lime-based renders may be a necessity in order to achieve the required compatibility with ancient renders and substrates. With the purpose of developing mortars for this application, metakaolin was added to lime mortars allowing for a faster application and hardening and, possibly higher durability whilst maintaining compatibility requisites. Metakaolin from two different producers was characterised and mortars containing air-lime, metakaolin and siliceous sand were formulated with different compositions. A testing campaign for determination of mechanical strength and capillary absorption was carried out. Following the obtained results, application of lime-metakaolin mortars both in conservation and in new build, as a sustainable alternative, is discussed.

1 INTRODUCTION

Metakaolin is obtained from the calcination of kaolinitic clays at temperatures in the range of 700-800ºC (Badogiannis 2005, Sabir 2001), high enough to allow for loss of hydroxyls but below temperatures that cause the formation of a vitreous phase and crystallization of other phases such as mullite. The raw-material for its production is available in Portugal, especially in the north and centre of the country (Ferraz 2004, Gomes 1990), although many quarries are no longer active due to lack of demand. However, a growing scientific interest in the use of metakaolin in mortars and concretes, in order to improve mechanical strength or reduce alkali-silica reaction (Fortes-Revilla 2006, Kim 2007, Ramochlan 2000, Silva 2006), together with the prospective lack of traditional pozzolanic materials such as fly ash and silica fume, are inducing the industrial sector towards metakaolin production.

In building conservation practice, there is some difficulty in formulating compatible mortars for use in renders and joints, due to requisites of low elastic modulus, sufficient flexural strength and adequate behaviour in terms of water intake and drying. Chemically, materials must also guarantee compatibility issues. For these reasons air lime is the most adequate binder, however it encloses some problems such as slow setting, inability to harden under water and lack of durability. The use of pozzolans in lime mortars is a matter of recent studies (Fortes-Revilla 2006, Velosa 2006) and results suggest that, in adequate proportions, they produce an increase in mechanical strength and durability of mortars, meeting water intake and drying requirements. Additionally, these mortars have low cracking susceptibility (Veiga, in press), a factor of major importance, crucial in terms of efficiency towards limiting water absorption of walls and increasing durability.

Although formulations were made focusing on conservation mortars, these products (air lime and metakaolin) may also be used for mortars to be applied in new build, if formulations are altered to meet different requirements. The use of air lime in mortars is a contribution towards sustainability, due to lower temperatures used in the production process and lower CO_2 emissions; additionally, during the carbonation process, CO_2 is absorbed from the atmosphere (Holmes, 1997).

2 MATERIALS, MORTAR COMPOSITIONS AND CONDITIONING

Mortars were formulated with powdered commercial air-lime, a siliceous river sand and metakaolin from two different sources: commercialized, very pure, metakaolin of a white colour (K1) and a nationally produced metakaolin with light orange colouring (K2), described in Table 1. These products were characterized in terms of X-Ray Diffraction (XRD) and results revealed a similar composition of quartz, feldspars and muscovite, with an evident content of amorphous material.

Table 1: Characterization of metakaolin

Product	Colour	Apparent density (kg/m^3)
K1	White	315,0
K2	Light orange	638,8

Table 2 shows mortar compositions (in volume) and water/dry mortar ratio (W/M) in which both binders and aggregates are considered. Added water was calculated in terms of an adequate consistency, producing similar flow values (around 130), correspondent to adequate workability for this type of mortar. A lime mortar with a lime/sand volumetric ratio of 1:3 was used as comparison mortar. Ratios 1:1:4 (lime: pozzolan: sand) and 1:0,5:2,5 (lime :pozzolan: sand) were used taking into account that it does not act totally as a binder and results from other studies relative to lime consumption (Moropoulou 2004, Sabir 2001). Only one ratio was tested with MK1, whilst two different ratios were tested with MK2.

Table 2: Mortar composition

Product	Lime	K1	K2	Sand	W/M (% weight)
L	1	-	-	3	15
MK1	1	1	-	4	21
MK2A	1	-	1	4	15
MK2B	1	-	0,5	2,5	15

No cement mortars were included in this test programme, but a comparison was made with a cement mortar, C, with a volumetric ratio 1 : 4 (cement : sand), tested in a previous study [Veiga, 2003], following the same test methods.

Mortar specimens were prepared and conditioned in a climatic chamber following standard NP EN1015-11: Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar. Specimens were stored for the first 7 days at 20±2ºC, in a plastic bag and then maintained at the same temperature, but with a relative humidity of 65±5%. Mortars with no pozzolanic addition (L) were not stored initially in a plastic bag, as previous attempts to implement this, by the authors and by other researchers[1], resulted in a retarded hardening of pure lime mortars.

3 RESULTS AND DISCUSSION

Compressive and flexural strength testing was performed following standard NP EN1015-11: Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar. The dynamic modulus of elasticity was determined following Report LNEC 427/05-NRI and capillary absorption was tested following NP EN 1015-18: Meth-

[1] These results are not yet published.

ods of test for mortar for masonry – Part 18: Determination of water absorption coefficient due to capillary action of hardened mortar.

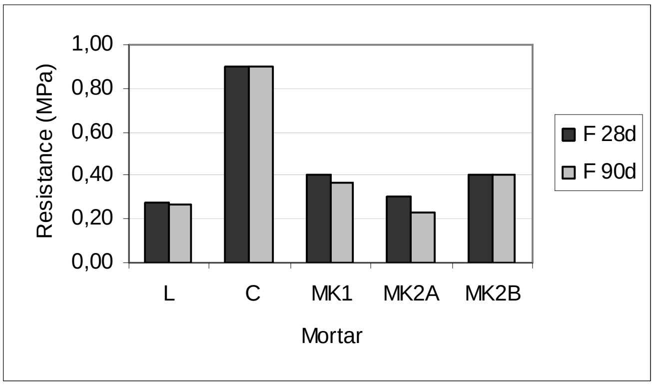

Figure 1: Flexural strength of mortars at 28 and 90 days

Results of the flexural resistance test indicate an increase in strength of mortars MK1 and MK2B in relation to lime mortar with no addition. However, results of MK2A, with a 1:1:4 ratio in volume were very similar to those of lime mortar. The decrease in flexural strength from the age of 28 days to the age of 90 days is a phenomenon that has been observed in other mortars, namely those containing pozzolans; reasons for this are unclear but may be linked with microcracking due to shrinkage, to which flexural strength is very sensitive (Veiga & Carvalho, 1994). The higher flexural strength displayed by mortar MK2B is due to the action of metakaolin as a binder, increasing binder/aggregate relation. Results achieved by cement mortar C, with a lower binder ratio, are significantly higher from the others.

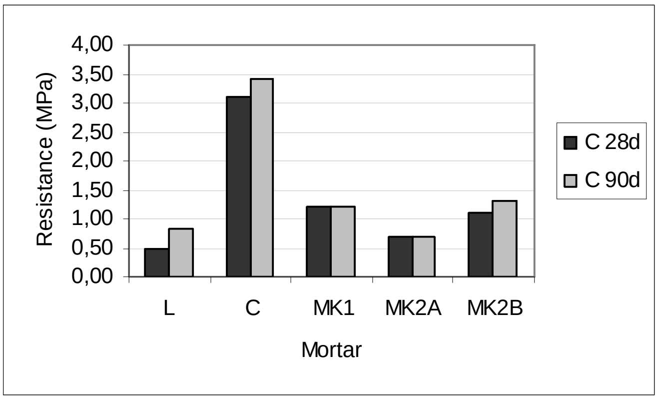

Figure 2: Compressive strength of mortars at 28 and 90 days

Compressive strength results show similarities with those of flexural strength, with a clear strength increase in mortars MK1 and MK2B in relation to mortar L, with no metakaolin, whilst mortar MK2A reveals an early strength increase in relation to mortar L, but attained strength stabilizes until the age of 90 days. At this age, compressive resistance of MK2A is lower that that of the comparison lime mortar. This property, in mortars with a 1:1:4 ratio (MK1 and MK2A) has no variation between the ages of 28 days and 90 days, probably due to partial action of metakaolin as an aggregate. Again, results attained by cement mortar reveal higher mechanical strength compared to those with other binders.

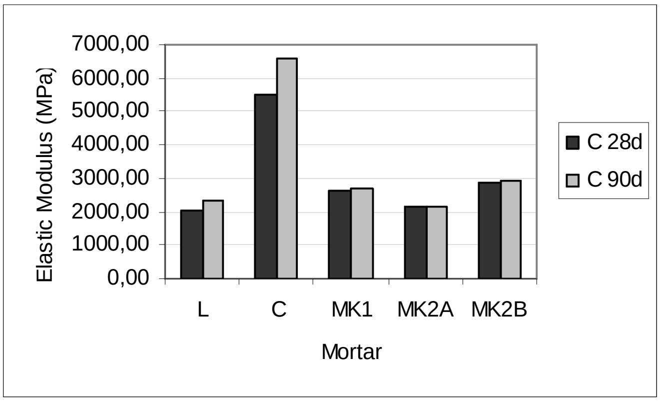

Figure 3: Elastic Modulus of mortars at 28 and 90 days

Elastic Modulus of all tested mortars with a lime binder is low, as desired, ranging from 2000MPa to 3000MPa, and variations from 28 days to 90 days are not significant. Using a cement binder the Elastic Modulus rises to values surrounding 6000MPa.

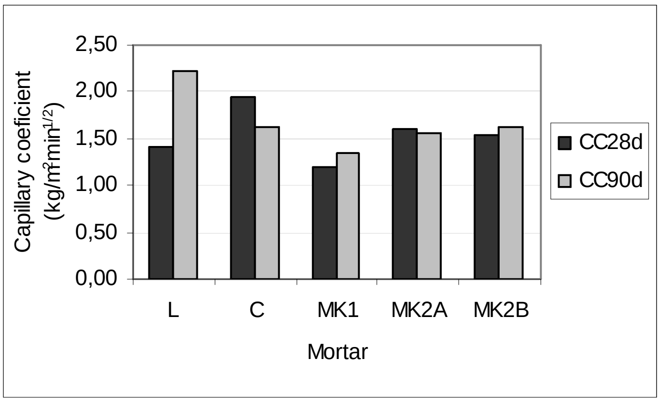

Figure 4: Capillary coefficient at 28 and 90 days

Initial capillary absorption of all mortars with metakaolin is similar, and with values lower than comparison mortars. At 90 days, possibly due to the development of a different pore structure in lime with pozzolan mortars in relation to mortars with no additions, capillary coefficient of mortar L is significantly higher than the others (Figure 4). The formation of products from pozzolanic reaction, with a different structure may induce this phenomenon. Capillary coefficient gives an indication on initial water absorption rate. Additionally, Figures 5 and 6 show that total water intake of mortar MK2B, at 90 days, is significantly lower than that of mortar L and drying is also faster.

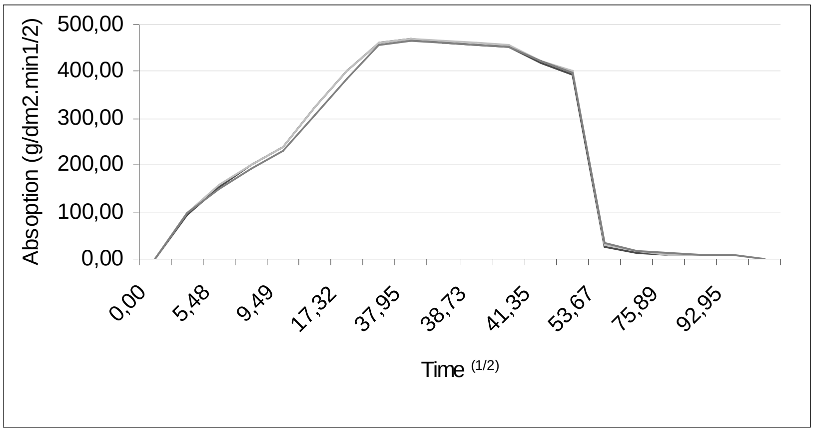

Figure 5: Capillary absorption and drying of lime mortar (L) at 90 days

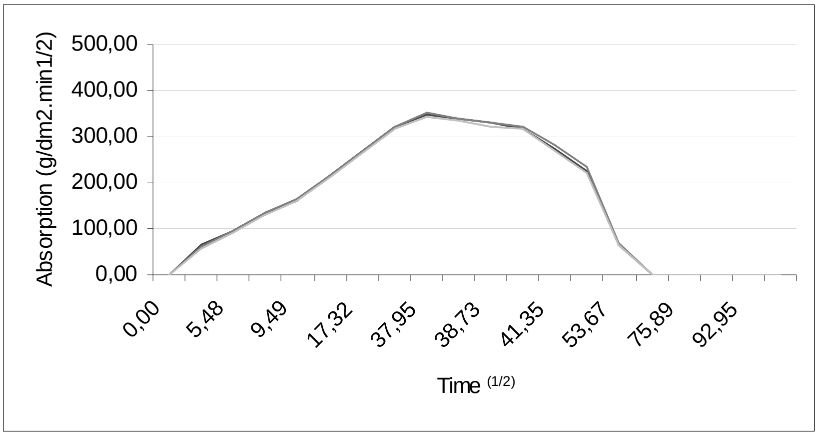

Figure 6: Capillary absorption and drying of MK2B mortar at 90 days

Although it is expected that pozzolanic additions increase mechanical strength of mortars, this did not occur with mortar MK2A. A possible explanation for this is that MK2 acted partially as an aggregate. In fact, taking into account the apparent density of lime (430kg/m^3) and of MK2 (638kg/m^3) and the fact that some of the lime will be used by carbonation and some by pozzolanic reaction, some of the pozzolan will not be involved in pozzolanic reaction due to lack of lime (CH), acting as an aggregate in the 1:1:4 (lime: pozzolan: sand) mix, and therefore increasing aggregate/binder ratio.

The obtained results were consistent, revealing an increase in mechanical strength of lime mortars with pozzolanic additions in all mortars except for MK2A and adequate behaviour in terms of water intake and drying.

4 CONCLUSIONS

Metakaolin is an adequate pozzolanic addition for lime mortars, providing adequate mechanical and water behaviour characteristics for application in conservation mortars. For this particular application cement mortars are inadequate, due to excessive elastic modulus and high content in soluble salts [Teutónico et al., 1994; Veiga et al., 2004; Moropoulou et al., 2005]. A further advantage of lime/pozzolan mortars is their lower environmental impact, when compared to cement mortars, due to lower CO_2 emission during production and CO_2 absorption by carbonation.

Further studies, taking into account cracking susceptibility and durability (climate and salts) must be undertaken.

An important conclusion that arises is that the use of greater percentages of pozzolan in a mortar doesn't necessarily imply improved characteristics. For each particular pozzolanic product there are specific formulations that produce better results for the application that is being considered.

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REFERENCES

Badogiannis, E. et al. 2005. Metakaolin as a main cement constituent. Exploitation of poor Greek kaolins. Cement & Concrete Composites 27: 171-181.

Kim, H., Lee, S. & Moon, H. 2007. Strength properties and durability aspects of high strength concrete using Korean metakaolin 21 (6): 1229-1237.

Ferraz, E.J. 2004. Caulinos de Alvarães: propriedades e aplicações cerâmicas. Dissertação apresentada na Universidade de Aveiro para obtenção do grau de Doutor em Geociências.

Fortes-Revilla, C., Martínez-Ramírez, S. & Blanco-Varela, M.T. 2006. Modelling of slaked lime–metakaolin mortar engineering characteristics in terms of process variables 28 (5): 458-467.

Gomes, C. F., Velho, J.A.G. 1990. Kaolin deposits of Portugal. Geociências, Revista da Universidade de Aveiro 5 (2): 27-36.

Holmes, S., Wingate, M.1997. Building with Lime. Intermediate Technology Pulications.

Moropoulou, A. et al. 2004. Evaluation of pozzolanic activity of natural and artificialpozzolans by thermal analysis. Thermochimica Acta 420: 135-140.

Moropoulou, A.; Bakolas, A.; Moundoulas, P.; Aggelakopoulou, E. 2005. Reverse engineering: a proper methodology for compatible restoration mortars. Proceedings of Workshop Repair Mortars for Historic Masonry, TC RMH. Delft: RILEM.

Ramochlan, T., Thomas, M. & Gruber, K. 2000.The effect of metakaolin on alkali–silica reaction in concrete 30 (3): 339-344.

Sabir, B.B., Wild, S. & Bai, J. 2001. Metakaolin and calcined clays as pozzolans for concrete: a review. Cement & Concrete Composites 23: 441-454.

Silva, A.S.2005. Degradação do betão por reacções álcalis-silica. Utilização de cinzas volantes e metacaulino para a sua prevenção. Tese de Doutoramento.

Teutonico, J.M. McCaig, I., Burns, C., Ashurst, J. 1994. The Smeaton Project: Factors affecting the properties of lime-based mortars, Bulletin of the Association for Preservation Technology 25 (3-4), pp. 32-49.

Veiga, M.R, Velosa, A. & Magalhães, A.C. Evaluation of mechanical compatibility of renders to apply on old walls based on a restrained shrinkage test. Materials and Structures. In press (online version available Jan 2007).

Velosa, A. L. 2006. Argamassas de cal com pozolanas para revestimento de paredes antigas. Doutoramento em Engenharia Civil, Universidade de Aveiro.

Veiga, M. R. & Carvalho, F. 1994. Argamassas de revestimento na reabilitação do património urbano. In 2º ENCORE, Encontro sobre Conservação e Reabilitação de Edifícios, Lisboa, LNEC. Vol. I: 195-206.

VEIGA, M. Rosário – Argamassas para revestimento de paredes de edifícios antigos. Características e campo de aplicação de algumas formulações correntes. Actas do 3º ENCORE, Encontro sobre Conservação e Reabilitação de Edifícios. Lisboa: LNEC, Maio de 2003.

Veiga, M. R.; Aguiar, J.; Santos Silva, A.; Carvalho, F. 2004. Conservação e renovação de revestimentos de paredes de edifícios antigos. Lisboa: LNEC, Julho 2004. Colecção Edifícios, CED 9.

Veiga, M. R.2005.Regras para a concessão de Documentos de Aplicação a revestimentos pré-doseados de ligante mineral com base em cimento para paredes. Lisbon: LNEC. Report 427/05-NRI.

Characterisation of external renderings of rammed earth construction in Algarve

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ABSTRACT**:** Rammed earth is a traditional construction material in the Algarve (South of Portugal), well adapted to climatic conditions in that region, with Mediterranean characteristics. A number of old village houses are built with this technology and some modern architects are beginning to adapt this kind of material to new construction, naturally fulfilling new requirements. This paper presents an analysis aiming at characterizing the exterior lime rendering of ancient rammed earth constructions in western Algarve. The study is centred on the search of useful references to the rehabilitation or repair processes, when anomalies occur due to the interaction between the rammed earth background and the rendering materials, as a result of their different characteristics and performance. Therefore, a reference is made to the methodology used to characterize samples extracted from five constructions in western Algarve, similar from a construction point of view.

1 INTRODUCTION

This paper is based on a survey and sample collection of exterior lime renderings from traditional buildings in western Algarve and of their rammed earth backgrounds. From this preliminary stage a set of samples was gathered for their physical, mechanical and chemical characterization in laboratory.

Within a Masters thesis in Construction of the first author at Instituto Superior Técnico, characterization tests were performed at the National Laboratory of Civil Engineering (LNEC), allowing the establishment of analysis criteria aiming at the comprehension of the degradation phenomena of these renderings.

2 SCOPE AND OBJECTIVES

Earth buildings play a particularly relevant role in the history of national construction within a specific scenario at the social, economic and geographic levels, which created adequate conditions to their expansion, namely in the South of Portugal (Alentejo and Algarve).

The main objective of the characterization process of the renderings is understanding the natural degradation phenomena and of how they are associated with the background characterization. As a result of this analysis a search was endeavored for clues on the adequacy of applying certain rendering compositions, either in rehabilitation scenarios or in new construction.

The collection of samples for the research aiming at physically and mechanically characterizing rammed earth construction followed the following criteria: 1. type of background: rammed earth; 2. type of coating: exterior; 3. geographical area: western Algarve; 4. type of construction: current dwelling of 1 to 2 storeys above ground; 5. construction period: from 1850 to 1950.

Five buildings (Figures 1 and 2) were selected, regularly spread within the geographical area under analysis and the following locations: Sesmarias; Arão; Montes de Cima; Pincho; Porches.

Figure 1. Geographical location of the five buildings under analysis


Figure 2. Buildings studied (from left to right): Porches, Sesmarias, Montes de Cima, Arão e Pincho

3 CHARACTERIZATION METHODOLOGY

The methodology used to characterize the renderings comprised the following major steps:

1. Field survey:

Buildings selection and systematic collection of renderings and earth backgrounds samples in the 5 cases under analysis.

2. Laboratorial stage (performed at LNEC):

Execution of tests for physical and mechanical characterization of the collected renderings (a total of 30 valid samples): capillarity (water absorption) and subsequent drying; acid dissolution to estimate the mix ratio - percentage of insoluble residue (RI); porosity and porosimetry; stratigraphy analysis; compressive strength (this test was also performed on the earth backgrounds).

As samples were irregular in shape and easily disintegrable, standard test methods could not be applied to calibrate water absorption and compressive strength, which demand well defined shapes and some cohesion. Therefore recently developed tests from LNEC for ancient renderings were used, within on-going research projects (Valek & Veiga, 2005; Veiga et al., 2004).

4 TESTS CAMPAIGN

4.1. Capillary absorption and drying - Renderings

The first stage effectively established response patterns to water contact, by simulating a natural scenario of rain exposition. It defined the level and rate of water absorption of applied renderings and it correlated it with the drying rate. This analysis is especially relevant given the high susceptibility to water of rammed earth backgrounds. It also evaluated the expected water retention period within the rendering layer after rain water absorption and in what way it can affect the integrity of the earth background. The technique used, described and validated in previous work (Veiga et al, 2004), is pictured in Figure 3.

The 15 samples - 3 for each building selected – were weighed at the absorption stage and after drying, under similar temperature and humidity conditions.

The results obtained are translated into capillary absorption and drying diagrams (Figure 4). The contact capillary coefficient mean values are presented in Table 1.

4.2. Acid dissolution - percentage of insoluble residue (% RI) - Renderings

The aim of these tests is the approximate determination of the composition of the renderings collected (Jedrzejewska, 1960). The dissolution with hydrochloric acid (HCl) results in a non-soluble fraction, named insoluble residue (RI), which approximately corresponds to the non-calcareous aggregates. The test was performed in 3 of the 5 buildings under analysis Pincho, Montes de Cima and Sesmarias (Figure 5).

Figure 3. Water absorption and drying process

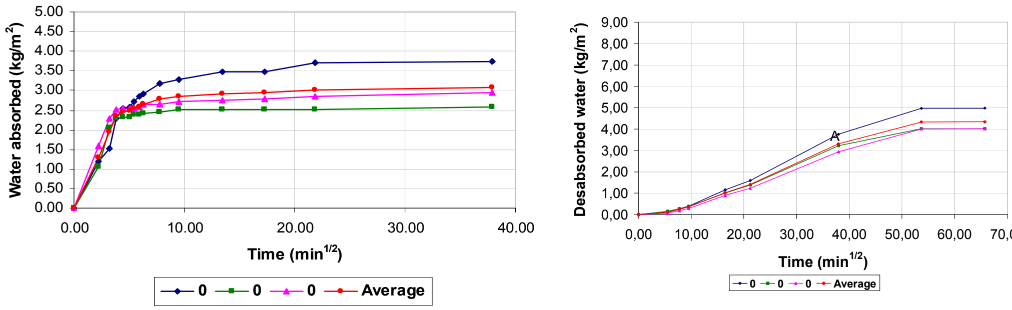

Figure 4. Water absorption (left) and drying (right) diagrams

Table 1. Contact capillary coefficients

	Contact capillary coefficient (kg/m^2.min$^{1/2}$) - Average			Overall absorption (kg/m^2)
	Cc 5	Cc (90-10)	Cc24	
Sesmarias	0.57	0.14	0.08	3.09
Arão	0.35	0.33	0.10	4.01
Montes de Cima	1.69	0.36	0.22	7.58
Pincho	0.67	0.21	0.11	4.37
Porches	0.89	0.03	0.06	2.42

Figure 5. Disintegration of the rendering sample (left), stabilization of the dried samples (centre) and decantation of the insoluble residue fraction obtained through acid

The ratio of insoluble residue in acid is expressed as a percentage by (c_1 - c) / m x 100, where m is the mass of the sample, c is the mass of the container empty, and c_1 is the mass of the container plus the insoluble residue after drying.

The results of these tests are presented in Figures 6 and 7 and Table 2 presents the weight proportions of the renderings tested.

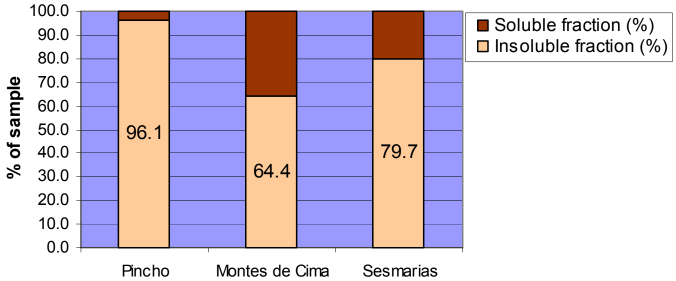

Figure 6. Soluble and insoluble (RI) fractions of the 3 samples

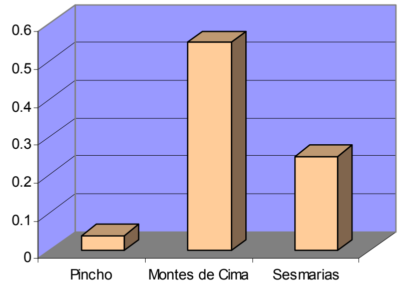

Figure 7.Ratio soluble fraction / insoluble fraction

Table 2. Weight proportions of the renderings

	Binder (lime)	Aggregates
Pincho	1	33,3
Montes de Cima	1	2,4
Sesmarias	1	5,3

4.3. Porosity and porosimetry - Renderings

Other laboratory tests were performed to relate the permeability of the samples with their porosity. The results of the water absorption were also related with a porosimetry analysis.

Porosity of a sample is understood as the ratio between the pores volume within the sample and its apparent volume. The volume of pores was determined by the volume of water that penetrates the sample when it is immersed (open porosity).

The porosity and porosimetry structure of six samples from three buildings (Porches, Sesmarias and Montes de Cima) was determined, using mercury intrusion porosimetry (MIP) (Figure 8).

Figure 8. AUTOSCAN60 equipment (left) and filling apparatus (right)

The samples tested were first subjected to a drying process in an oven at around 70 ºC for 72 h, after which they were positioned inside a desiccator cabinet until they were tested, in order to keep the internal moisture level.

The dried samples were weighed, positioned inside the test cell (penetrometer) and then in the AUTOSCAN60 equipment; later on they were degasified for 30 minutes at room temperature, the test cells were filled with mercury and the pressurizing process started. The limit values achieved by pressure and the respective pores radiuses were then determined.

In Table 3 the results obtained for the three renderings tested are summarized. Figure 9 presents the porosimetry distribution determined for each one of the samples tested.

4.4. Stratigraphy analysis - Renderings

The stratigraphy analysis performed in laboratory (Figure 10) allowed a general survey of the number of layers applied in the exterior coatings of the five buildings under analysis (one sample of each), of the materials used and the register of eventual maintenance or repair interventions the renderings may have been subjected to (Baronio et al, 1989).

Table 3. Summary of the results of porosity

Sample	Bulk density (kg/m^3)	Density (kg/m^3)	Porosity (%)
PORC-1 (Porches)	2257	2608	13,5
PORC-2 (Porches)	2281	2628	13,2
SES-1 (Sesmarias)	2160	2625	17,7
SES-2 (Sesmarias)	2144	2643	18,9
C-1 (Montes de Cima)	1750	2602	32,7
C-2 (Montes de Cima)	1744	2606	33,1

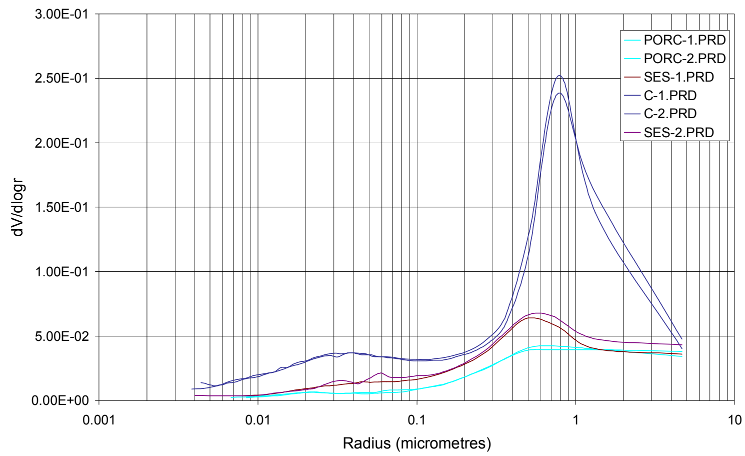

Figure 9. Porosimetry distribution curves by MIP of the samples tested

Figure 10. Observation with binocular magnifying glass

Preliminary to the analysis with binocular magnifying glass procedures of selection and preparation of the dried samples, impregnated with resin, were performed (Figures 11 and 12).

The observation with binocular magnifying glass allowed the visual register of a stratigraphy section of the various renderings, as shown in Figure 13.

4.5. Compressive strength - Coatings and rammed earth

This test aimed at establishing direct relationships between the strength capacity of existing coatings in the buildings selected and strength capacity of the rammed earth background (Veiga et al, 2004).

From the point of view of the analysis of the renderings durability and performance, it is interesting to calibrate the relationship between the mechanical characteristics of the various main elements of the wall, as well as the possible trends detected in that characterization. So, the study was focused on determining the compressive strength both of coatings and rammed earth.

Figure 11. Vacuum chamber (left) where the samples are kept for 24 h before they are impregnated with epoxy resin and samples after the impregnation (right)

Figure 12. Samples cut and polished (left) and their observation with a binocular amplifying glass (left)

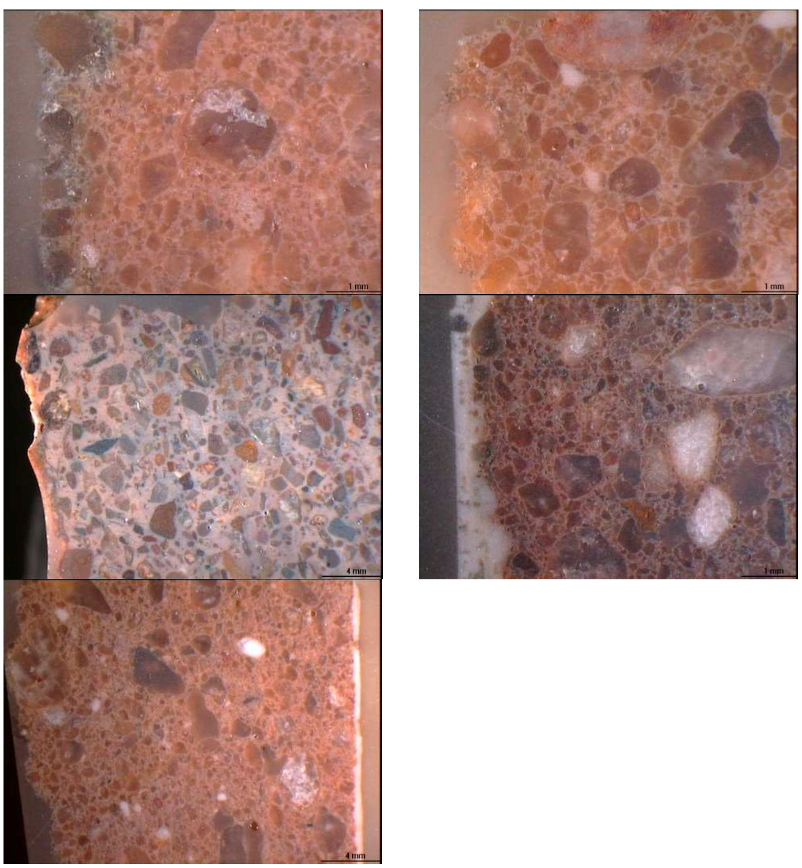

Figure 13. Stratigraphy sections of the renderings: Sesmarias, Arão, Montes de Cima, Pincho and Porches

For each of the five buildings and their respective coatings three samples were tested (Figure 14). Results are summarized in Table 4.

Figure 14. Equipment and test samples (left) and coating sample after failure (right).

Table 4. Summary of the results of compressive strength (coatings and background)

Coating Sesmarias - Rendering		Background Sesmarias - Rammed earth	
$Rm_{average}$ (MPa)	2,1	$Rm_{average}$ (MPa)	1,1
Coating Arão - Rendering		Background Arão - Rammed earth	
$Rm_{average}$ (MPa)	2,1	$Rm_{average}$ (MPa)	1,3
Coating Montes de Cima - Rendering		Background Montes de Cima - Rammed earth	
$Rm_{average}$ (MPa)	3,1	$Rm_{average}$ (MPa)	0,8
Coating Pincho - Rendering		Background Pincho - Rammed earth	
$Rm_{average}$ (MPa)	2,0	$Rm_{average}$ (MPa)	1,3
Coating Porches - Rendering		Background Porches - Rammed earth	
$Rm_{average}$ (MPa)	4,1	$Rm_{average}$ (MPa)	2,7

5 ANALYSIS OF THE RESULTS

One of the main aspects concerning renderings degradation processes is their susceptibility to water. The analysis of the water absorption and drying tests leads to the following conclusions:

1. Invariably the highest absorption rate occurs in the initial water absorption period (first 5 minutes), implying a significant capillarity of the renderings analyzed;
2. Almost total absorption of the coating is achieved after a reduced period (under 25 minutes); the remaining water absorption process occurs at a very low rate;
3. Generally, drying periods are significantly larger than absorption periods and rates are smoother over time;
4. Therefore, there is a very significant difference between the period during which saturation of the coating occurs throughout its thickness and that corresponding to total drying of the previously saturated coating; this implies, during the saturation / drying cycle, a water retention period in the interface between the coating and the rammed earth background.

In the universe of rendering tested for insoluble residue determination (5 buildings and their renderings) a higher initial water absorption rate seems to be associated with greater binder content. The same happens when overall absorption of each coating is analyzed. This conclusion contradicts the usual assumption that relates higher binder content with higher compactness and therefore lower absorption rate and lower overall absorption.

In the same universe there is no perception of an unequivocal relationship between water absorption rate and porosity level. *Há, se em conjunto com a porosimetria, como se vê a seguir.*

Porosimetry results reveal coherence with those of capillary absorption: the Montes de Cima rendering presents a very concentrated porosimetry distribution in the range between 0,5 and 1 μm and also a high porosity level, which explain the high initial capillary absorption rate, as well as the overall absorption. The remaining coatings analyzed showed very regular distributions in terms of pores dimensions, leading to low porosity levels, which explain low overall absorption, and relatively small average pore radius. This kind of porous structure leads to slower absorption rates, evidenced by the reduced capillary coefficients (Magalhães et al, 2004; Arandigoyen & Alvarez, 2006).

Compressive strength results (coatings and background) led to the following conclusions:

1. In every building there is a relevant difference in terms of compressive strength between the renderings and the rammed earth (the latter is the least resistant);
2. Exterior coatings show very high compressive strength; this generates excessive interfacial stresses with the rammed earth background, as a result of different deformation capacities (Binda et al, 2000; Lanas & Alvarez, 2003), promoting loss of adherence between these materials and frequent spalling (amply witnessed on site) in this type of building;
3. In the Sesmarias, Montes de Cima and Pincho coatings there were higher compressive strength levels in those cases where the binder content was higher.

There is no unequivocal relationship between the renderings compressive strength and their porosity.

6 CONCLUSIONS

The present rebirth of rammed earth construction has various reasons, connected with the acknowledgement of its advantages in terms of traditional construction identity to be maintained and of thermal and acoustic comfort it provides. However, it also reveals some drawbacks, namely concerning their low resistance to earthquakes and susceptibility to water action.

The universe of buildings tested is limited (5 cases) and is dispersed through Western Algarve. This dispersion is associated to variations in the characterization of the background and coating materials, namely in terms of the grading curve of the earth mixes. Even though these variations are noticeable, tests performed in laboratory revealed the existence of response patterns common to all the buildings tested, either in terms of water presence (and subsequent drying) or materials compressive strength. The following are underlined:

1. Water absorption is relatively quick, revealing great susceptibility to water of the renderings analyzed;
2. Drying is very slow, implying long water retention periods in the coating thickness, promoting its absorption by the background material (rammed earth) and leading to a progressive loss of compactness and cohesion of this material;
3. Compressive strength of the coatings is much higher than that of background material, leading to stresses in the interface that promote precocious loss of adherence, cracking and spalling of the coatings.

7 REFERENCES

ARANDIGOYEN, M.; ALVAREZ, J. "*Blended pastes of cement and lime: pore structure and capillary porosity*". Applied Surface Science, 252, 2006, 8077-8085.

BARONIO, G.; BINDA, L.; FURLAN, V. "*Gli intonaci e i colori delle siedlungen di Bruno Taut. L'Edilizia*", Ottobre 1989, anno 3. In Studies on mortars sampled from historic buildings. Selected papers 1983-1999, vol I. Politécnico di Milano, Dipartamento di Ingegneria Strutturale.

BINDA, L.; SAISI, A.; TIRABOSCHI, C. "*Investigation procedures for the diagnosis of historic masonries*". Construction and Building Materials, 14, 2000, 199-233.

JEDRZEJEWSKA, H. *"Old mortars in Poland: a new method of investigation"*, Studies in Conservation, 1960, Vol. 5, nº 4, pp. 132-138.

LANAS, J.; ALVAREZ, J.J. "*Masonry Repair lime-based mortars: Factors affecting the mechanical behavior*" Cement and Concrete Research, 33, 2003, pp. 1867-1876.

MAGALHÃES, A. C. & MORAGUES, A. & VEIGA, M. R. *"Application of some methods on evaluation of porous systems of wall renderings"*, VII Congreso Internacional de Rehabilitación del Patrimonio y Edificación, Lanzarote, July 2004.

VALEK, J. & VEIGA, M. R. *"Characterization of mechanical properties of historic mortars"*, STREMAH 2005 - Ninth International Conference on Structural Studies, Repairs and Maintenance of Heritage Architecture, 22 / 24 June 2005, Malta.

VEIGA, M. R. & MAGALHÃES, A. & BOSILIKOV, V. *"Capillarity tests on Historic mortar samples extracted from site. Methodology and compared results"*. 13th International Masonry Conference, Amsterdam, July 2004.

Environmental life cycle assessment of concrete made with fine recycled concrete aggregates

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ABSTRACT: The majority of worldwide structures use concrete as its main material. This happens because concrete is economically feasible, due to its undemanding production technology and ease of use.

However, it is widely recognized that concrete production has a strong environmental impact in the planet. Natural aggregates use is one of the most important problems of concrete production nowadays, since they are obtained from limited, and in some countries scarce, resources. In Portugal, although there are enough stone quarries to cover coarse aggregates needs for several more years, supplies of fine aggregates are becoming scarcer, especially in the northern part of the country.

On the other hand, as concrete structures' life cycle comes to an end, an urgent need emerges to establish technically and economically viable solutions for demolition debris, other than for use as road base and quarry fill.

This paper presents a partial life cycle assessment (LCA) of concrete made with fine recycled concrete aggregates performed with *EcoConcrete* tool. *EcoConcrete* is a tailor-made, interactive, learning and communications tool promoted by the Joint Project Group (JPG) on the LCA of concrete, to qualify and quantify the overall environment impact of concrete products. It consists of an interactive Excel-spreadsheet in which several environmental inputs (material quantities, distances from origin to production site, production processes) and outputs (material, energy, emissions to air, water, soil or waste) are collected in a life cycle inventory, and are then processed to determine the environmental impact (assessment) of the analysed concrete, in terms of ozone layer depletion, smog or "greenhouse" effect.

1 INTRODUCTION

The construction industry is known as being environmentally inefficient. The intensive extraction of raw materials for the production of materials involved in buildings execution, the energy needed to perform heavy industrial processes and the resulting debris, both from new construction and demolition of old one, all contribute to a strong penalization of the environment.

One of the materials most used in the construction of structures is concrete because of its ease of production, low-demand technologies and easy-to-obtain materials needed in its production, leading to low production costs.

However, in order to produce concrete it is necessary to extract stone both for cement production and to be used as aggregates. Usually, concrete fine aggregates are obtained from the extraction of sand from river beds or maritime coats. However, this activity brings along severe environmental problems: the alteration of the water flow in rivers or of the tides in seas leads to the erosion of the margins, with direct consequences on the nearby infrastructures.

Even though in Portugal and particularly in the south of the country there are relevant amounts of natural sand for extraction, some recent studies (Dias, 2005) point out the need to implement more restrictive measures in terms of extraction, in order to invert the destructive process of the coasts that is being felt nowadays.

With the objective of checking the technical viability of replacing fine natural aggregates (FNA) with equivalent recycled aggregates (FRA) in concrete production, a research was endeavored at Instituto Superior Técnico aiming at evaluating the performance of concrete made with different ratios of replacement.

Notwithstanding the fact that the technical viability was proved by the results obtained (Evangelista & Brito, 2006, 2007), the economic and environmental viability needed to be checked. As a matter of fact it is not consensual nowadays that recycling is one of the paradigms in sustainability. Pereira (2004) refers clearly that in his view recycling is not a solution to the problem. Even though recognizing the benefits of this practice he states that "is not The solution". Even though recycling leads to a reduction in the use of abiotic materials, it is possible that waste treatment for future applications and/or the worst quality of the resulting products may jeopardize their reuse both in economic and environmental terms.

This paper presents a Life Cycle Assessment analysis performed on concrete with fine recycled concrete aggregates, in order to understand the real benefits brought by concrete recycling for the production of fine aggregates. This type of analysis corresponds to evaluating the various environmental impacts of each product, from its "cradle" to its "grave". The LCA analysis thus takes into account every resource and material consumed both directly (in its creation) and indirectly in all the accessory activities needed for its creation (extraction, transformation, etc.). This quantification allows the establishment of the environmental damage during its life cycle. According to the Environmental Protection Agency (EPA, 2006), the life cycle of a product is divided in four main stages:

- obtaining the raw materials - included are the resources consumed, as well as the materials and energy spent in the extractive and transport activities;
- production - included are the activities of raw materials transformation, product execution and its transport and conditioning to its destiny;
- use, reuse and maintenance - where the activities and consumptions resulting from the use and quality maintenance of the product are quantified;
- recycling and waste treatment - where the impact of the activities associated with destroying the product, as well as the impact of the resulting waste, are evaluated.

2 THE ECOCONCRETE TOOL

2.1 *General description of the software*

In order to perform LCA analyses the software Ecoconcrete, produced by the Joint Project Group (JPG), was used. This is a design tool that implements the LCA methodology specifically for the concrete production sector. Basically it is a spreadsheet within the MSExcel® platform in which data concerning production, transport, application, maintenance, and end-of-life cycle are inserted giving out the various environmental impacts felt.

To evaluate the concrete environmental impact Ecoconcrete resorts to one of three available analyses: CML, EDIP or Eco-indicator 99.

The CML methodology was developed at the Institute for Environmental Sciences of the Leiden University in Holland and proposes that the environmental impact of a product is made according to the negative effect that the different sub-products from its production have in eight different phenomena: abiotic depletion; acidification; global warming; ecotoxicity; eutrophication; human toxicity; production of photo-oxidant agents; destruction of the ozone layer. Additionally, the CML analysis predicts the concrete environmental impact by measuring the energy spent during its life cycle, as well as the chemical and non-chemical waste produced.

The EDIP (Environmental Design of Industrial Production) project, developed in partnership by various Danish entities, similarly to the CML methodology, aims at evaluating the impact during the life cycle by measuring the effects of a set of pre-established phenomena: global warming; destruction of the ozone layer; acidification; nutrients enrichment; eco-toxicity; human toxicity; photochemical ozone formation; waste gross production; toxic waste production; nuclear waste production; sludge slag and ash production.

The main difference between these two methodologies lies in the Life Cycle Inventory each one resorts to and specifically in the quantification of the impacts that the different activities cause.

Contrarily to the previous methodologies, that correspond to intermediate stages of the LCA analysis, needing post-interpretation taking into account the various parameters in question, and are therefore slow and complex (Goedkoop, 1995), Eco-indicator 99 is supposed to be a final analysis procedure, giving an environmental score to a product or process, with an easy and objective interpretation.

Eco-indicator 99 is obtained by evaluating the environmental damage in natural resources, public health and the ecosystems. The weight of each one was established through an enquiry to experts involved in a Swiss group of LCA (Baayen, 2000):

– damage to public health and the ecosystems have the same weight;
– damage to natural resources has a weight sensibly half of the previous ones.

2.2 *Limitations of Ecoconcrete*

Ecoconcrete is presently in its version 1.1. This tool is still under development and therefore there are still some factors that limit its use.

To begin with the software possesses only a limited database in what concerns elements to be evaluated. At the moment it is only possible to study four types of prefabricated concrete elements and four types of cast in situ concrete elements. Any other element that may involve different execution procedures or fabric processes is nor available yet.

Secondly the only environmental costs already inventoried from "birth" (raw materials extraction) to "gateway" (beginning of transport to destination) are those concerning three distinct types of cement (CEM I 52.5R, CEM II/A-L 32.5R and CEM III/A-42.5).

Finally, the software does not allow the direct prevision of recycled aggregates in concrete production. The only way to take into account this type of recycling is at the end of the life cycle of the product at its demolition.

3 ANALYSIS PERFORMED

3.1 *Adaptations implemented*

Because of the existing limitations of the software, adaptations were needed, both in terms of the composition of the concrete mixes under analysis and in the way the different component materials were taken into account.

The case study element selected was a 1 m^2 solid slab 0,25 m thick and with a reinforcement ratio of 70 kg/m^3.

To take into account the fact that the type of cement used in the experimental campaign (CEM I 42.5R) was not considered in the software, cement type CEM I 52.5R was used, because its chemical composition is the one that is most similar to the one of the cement used in the tests. However, this choice implies that a different strength class is considered which may affect energy consumption and gas emissions, since the difference in strength between two cements of the same type is directly related to the fineness module and the clinker burning process. However, since all the mixes analyzed have the same cement ratio, the error is going to be the same for all of them, thus allowing for acceptable comparative analyses.

To simulate the use of recycled aggregates, it was assumed at the end of the life cycle of the element under analysis that only part of it would be recycled (quantified in mass) in the production of a new slab. The remaining would be dumped. Therefore, knowing the content in fine recycled aggregates of each mix and the weight of the slab, it was possible to estimate the recycling ratio to be used as input in the software. It must also be stated that the transport distances, both for obtaining raw materials and dumping / recycling, were adapted: on the one hand, the use of recycled material on site reduces or even nullifies the distance needed to collect the fine aggregates; on the other hand, by using part of the recycled material on site, the quantity of material to be dumped is reduced (given the software limitations, this was considered by reducing the distance to the dumping site proportionally to the recycling ratio corresponding to each concrete mix). Table 1 presents the final estimate results.

Table 1. Estimate data used as input for Ecoconcrete

	Composition		
	BC	B30R	B100R
Fine aggregates content (kg/m^3)	664	610	488
Fine recycled aggregates (FRA) content (kg/m^3)	0	148	488
Distance from natural aggregates production headquarters (km)	100	70	0
Recycling ratio (%)	0	6,2	21,4
Distance from dumping ground (km)	50	46,9	39,3

3.2 *Results obtained*

Ecoconcrete quantifies the environmental impacts of the different stages of the element's life as well as the use of the various raw materials throughout the whole period, estimated as 50 years for practical terms. However and since in principle each mix will have a different service life due to its durability-related characteristics, the environmental impacts were estimated in terms of each year of the life cycle of the element. To do that the expected service life of each concrete mix was estimated based on its chloride diffusion coefficient. Since the concentration of chlorides at a given age t and depth x is given by equation (1) (BREU, 1993), it follows that service life (i.e. the time needed for a given chloride concentration (D_c) to occur at the reinforcement level) is inversely proportional to the chloride diffusion coefficient (D_{nssm}).

$$C(x,t)=C_0\left\{1-\mathrm{erf}\left(\frac{x}{2\sqrt{D_c.t}}\right)\right\} \tag{1}$$

Therefore the estimated service life of each mix, admitting 50 years that the reference concrete BC (without recycled aggregates), is given in Table 2.

Table 2. Estimated service life for the different concrete mixes

	BC	B30R	B100R
D_{nssm} (cm^2/s)	$1{,}8\times10^{-11}$	$2{,}0\times10^{-11}$	$2{,}4\times10^{-11}$
Service life (years)	50	44,7	37,4

3.2.1 *Analysis using the CML methodology*

The analysis of the CML parameters of energy consumption and waste emission (both chemical and non-chemical) shows that there is a significant reduction of these values when FRA are included in the mix. However, if the lower durability of these mixes is taken into account, it is concluded that yearly environmental costs increase with FRA inclusion, indicating that gains obtained with recycling do not compensate the lower longevity of the material. Nonetheless, these results may be justified by the present limitation of the software that led to the consideration of unrealistically low replacement ratios (only 21% for the concrete mix with integral replacement of FNA with FRA, B100R).

In terms of the environmental parameters specified by CML, Table 3 shows that there is a linear decrease of total impacts with the replacement ratio (around 7% for B30R and 20% for B100R). However, when taking into account the lower durability of mixes with FRA, the trends are inverted and the reference concrete (BC) becomes the "cleanest" and B100R the "dirtiest".

3.2.2 *Analysis using the EDIP methodology*

The comparative analysis of the various results obtained for each of the concrete mixes analyzed is shown in Table 4. The variations of each of the parameters are within the same range as those presented in the CML methodology. This is was expected since these methodologies determine the impacts through linear combinations of the various impacts included in the LCA and the difference in absolute values is only due to the different life cycle inventories (LCI) used.

Taking into account the expected service life of each of the mixes, the benefits brought by the incorporation of FRA seem to be insufficient to compensate for the losses due to their lower durability. Again this is probably a misleading result because of the artificially low replacement ratios inserted as data because of the limitations of the software.

Table 3. Relative changes of the environmental parameters of the CML methodology

Impact parameter	BC	B30R	B100R
Destruction of the ozone layer	-	-6.4%	-19.1%
Global warming	-	-6.9%	-21.0%
Human toxicity	-	-6.9%	-20.6%
Acidification	-	-7.2%	-21.7%
Eutrophication	-	-7.6%	-23.0%
Production of photo-oxidant agents	-	-6.7%	-20.3%
Aquatic toxicity (fresh water)	-	-6.8%	-20.4%
Aquatic toxicity sediments (fresh water)	-	-6.7%	-20.1%
Ground eco-toxicity	-	-6.8%	-20.7%
Abiotic depletion	-	-6.6%	-19.7%

Table 4. Relative changes of the environmental parameters of the EDIP methodology

Impact parameter	BC	B30R	B100R
Destruction of the ozone layer	-	-6,4	-19,1
Aerial human toxicity	-	-7,5	-22,3
Global warming	-	-6,9	-21,0
Acidification	-	-7,3	-21,8
Nutrients enrichment	-	-7,4	-22,2
Chronic aquatic toxicity	-	-4,7	-15,1
Acute aquatic toxicity	-	-4,7	-15,1
Chronic ground eco-toxicity	-	-7,2	-23,2
Acute ground eco-toxicity	-	-7,5	-22,3
Aquatic human toxicity	-	-6,9	-21,5
Ground human toxicity	-	-7,6	-22,5
Production of photo-oxidant agents	-	-6,9	-20,7
Overall waste	-	-8,3	-27,1
Toxic waste	-	-5,2	-16,8
Nuclear waste	-	-3,3	-10,6
Sludge slag and ashes	-	-7,0	-22,7

3.2.3 *Analysis using Eco-indicator 99*

As referred before, Eco-indicator 99 classifies a product by giving it an environmental rating. Even though this rating is technically hard to interpret, it is an efficient way of establishing comparisons between various alternatives and pointing out the most environmentally efficient. It is clearly tailored to inform the final consumer as opposed to being analyzed by the entities associated with the production. Results are summarized in Table 5.

Concrete mixes with FRA show a better rating than the reference concrete and the more so the greater the replacement ratio. These results agree with those of the two other methodologies. Similarly to those methods, their lower durability leads to a yearly worse performance (Table 6). Again this has to do with the way the problem was stated and the limitations of the software.

4 CONCLUSIONS

The Life Cycle Assessment analyses are an excellent way of quantifying the real impact that a given product has over the environment, from the onset of the raw materials extraction to its destruction and post-processing. To be valid, these analyses must be based on ample and reliable data bases (Life cycle inventories).

Ecoconcrete uses two of the existent LCI's: CML and EDIP. Their differences basically have to do with the value attributed to the damage caused by the activities and products inventoried.

Since Ecoconcrete is still under development some of the data concerning the problems under analysis had to be introduced indirectly with some detriment to the analysis presented. As a consequence, the results under-evaluate the benefits brought by the incorporation of recycled aggregates, in particular at the end of the life cycle of the structure, where it was necessary to state lower recycling ratios than those actually existing.

Table 5. Absolute results of the Eco-indicator 99 analysis for all concrete mixes analyzed

	BC	B30R	B100R
Cement	3,810	3,810	3,810
Aggregates	0,100	0,097	0,090
Admixtures	0,106	0,106	0,106
Reinforcement	1,463	1,463	1,463
Water	0,000	0,000	0,000
Transport constituents	0,930	0,831	0,653
Fabrication	0,104	0,104	0,104
2, Transport to site	0,000	0,000	0,000
3, Construction	0,104	0,104	0,104
4, Maintenance	0,000	0,000	0,000
5, Demolition	0,806	0,787	0,745
6, End of life scenario	0,894	0,826	0,676
Total	8,316	8,128	7,750
Δ	-	-2,26	-6,81

Table 6. Eco-indicator 99 results taking into account the different service lives

	BC	B30R	B100R
EI99	8.316	8.128	7.75
EI99 / ano	0.166	0.182	0.207
Δ (%)		9.33	24.59

A determining factor in the impact of concrete with FRA is the lower use of natural aggregates, with a consequent decrease of the impacts from their extraction. This was not quantified in the present version of the software since the input does not allow a decrease in the amount of natural aggregates without repercussions in the overall composition of the mix.

Nevertheless, the LCA analyses performed pointed consistently to an environmental benefit resulting from the replacement of FNA with FRA, even though overbalanced by the lower service lives of concrete mixes with FRA. For the reasons given above due to the present limitation of the Ecoconcrete software, it is believed that this last trend may be reversed.

5 REFERENCES

Baayen, H., 2000, *Eco-indicator 99: a damage oriented method for Life Cycle Impact Assessment, Manual for designers*: Dutch Environmental Ministry

BREU P3091, 1993, *Assessment of performance and optimal strategies for inspection and maintenance of concrete structures using reliability based expert systems*, Final technical report.

Dias, J., 2005, *Evolution of the Portuguese coastal area: autotrophic and natural impediments*, Scientific Meetings Journal, V. 1, pp. 7-27 (in Portuguese).

EPA, 2006, *Life cycle assessment: principles and practice*, Report EPA/600/R-06/060.

Evangelista, L. & Brito, J., *Carbonation and chloride penetration in concrete made with fine recycled concrete aggregates*, SIABE 06 - Iberian-American Symposium “Concrete in Structures”, Rio de Janeiro.

Evangelista, L. & Brito, J., *Mechanical behavior of concrete made with fine recycled concrete aggregates*, Cement and Concrete Composites, V. 29, n. 5, pp. 397-401.

Goedkoop, M., *The Eco-indicator 95: weighting method for environmental effects that damage ecosystems or human health on a European scale*, Final report, PRE Consultants B.V.

Goedkoop, M. & Spriensma, R., *The Eco-indicator 99: a damage oriented method for Life Cycle Impact Assessment*, Methodology Report, 3rd Ed., PRE Consultants B.V.

Pereira, F., *Illusions and paradoxes of recycling: the way to dematerialization of the economy*, , Waters & Waste Journal, n. 5/6 (in Portuguese).

Recycled aggregate production: remark and assessment of the economical advantage of a case study

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ABSTRACT: Recycled aggregate has been used in Italy to produce structural concrete after the related EU (European Union) directives was implemented at national level.
The use of recycled materials in construction has been scholarly proved to be economically advantageous.
This study focuses on mobile and fixed plants in Italy. The former applies only in case of debris recycling, whereas the latter can be competitive only when the recycling operation is complementary to the quarry activity. Production plants and demolition operations have been therefore investigated to show their technical and economic feasibility in different scenarios.

The outcome of this study is herein presented.

1 INTRODUCTION

Two major factors have been found to have considerably influenced the market of recycled aggregates in Europe and Italy: the EU and national regulations and environmental awareness.

The market of recycled aggregate has grown in countries with limited natural resources.

Waste disposal has also been one of the top EU political and environmental priorities. In the complex interaction between human activities and the environment, waste is proved to be one of the most environment-degrading products.

In 1972 the European Commission introduced measures on waste reduction, reuse and recycling.

In 2006, directive 2006/12/EC (European Commission) on waste was issued. It covers the scope of minimizing the waste, prevent hazardous waste, maximize reclamation, reuse, recycling and energy-recovery.

No specific directive refers to management and recycling of construction and demolition debris. However, in 1992 the European Commission listed debris among waste management priorities because of its growing amount.

Only recently, effective environmental policies have been implemented in Italy, even though relevant environmental issues started rising as early as the beginning of the 1970s.

In the 1980s the Government undertook the first significant measures to handle the waste management.

Because of the too many and dated laws on this regard, a new law was issued in 1982 aiming to provide a comprehensive regulatory frame of the subject: D.P.R. 915/1982 (It: Decreto del Presidente della Repubblica = En: Decree of the President of the Republic). Not only the new law replaced a 1940s law, but it also implemented some EEC (European Economic Community) directives on waste, such as the 75/442/EEC as an attempt to cover the management of different types of waste.

The 1982 law also promoted waste recycling and energy-recovery systems.

D.P.R. 915/1982 was further integrated and amended at different stages:

D.Lgs. n. 22/1997 (It: Decreto legislativo = En: Legislative Decree) also known as “Ronchi decree”, is a rundown of all previous regulations issued until that date, namely: 91/156/EEC on waste; 91/689/EEC on dangerous waste; 94/62/EC on packaging. Ronchi decree was the main regulatory reference on waste management in Italy until 2006.

The decree introduces two new concepts in Italy:

- waste management instead of disposal – to prevent waste production, promote recycling, reuse of energy, and to discourage landfill;
- the encouragement of voluntary agreements among waste management operators to achieve the aforementioned purposes.

A few other laws [Ammendola, G.] were issued in the following years in order to comply with the European regulations. It is worth to mention, the so-called "decree 30%" (Ministerial Decree 203/2003) which was conceived as an attempt to create better market conditions for recycled products.

It sets a minimum target for national and public agencies to meet at least 30% of their annual demand with recycled materials.

Nowadays the D.Lgs. n.152/2006, also known as "Environmental Code", is the main legislative reference regarding environmental issues.

Its text has been repeatedly amended by means of several implemental decrees, which caused the Code to be not completely applicable due to the coexistence of old and new rules.

With regard to the use of construction and demolition waste (C&D) in the building sector in replacement of raw materials, the first draft for technical standard came up in 1996. In the same years the UNI (Italian National Agency of Unification) "Building Commission" formed Working group 7 also called "Construction and demolition waste" to draw up "Guidelines for decreasing of construction and demolition waste in construction".

In 2000 the same Commission updated the standard UNI 10006 – "Road construction and maintenance - Technical provisions for the use of soil" thus providing standard instructions about the use of recycled aggregates for road construction.

However, a new norm EN 12620 "Aggregates for concrete" has already replaced it. It is an improvement of the former standards and provides a useful tool to determine characteristics and requirements of the aggregates for concrete.

This one has been further revised and its latest version, UNI 8520, defines the minimum requirements of the aggregate for concrete.

Table 1 shows the limit quantities set in the norm.

Table 1. UNI 8520 limit quantities

Use rate	Source	Strength category
Total or partial use	Demolition of buildings (debris)	≤C12/15
Total or partial use	Demolition of concrete elements	≤C20/25
≤ 10%	Demolition of concrete elements	≥C20/25
≤ 5%	Demolition of buildings (debris)	≥C20/25

In September 2005, D.M. 14.09.2005 (It: Decreto miniteriale = En: Ministerial Decree) named "Technical Norms for construction" was issued. It replaced previous norms and incorporated some European standards such as UNI EN 12620. This law contains important data about how to use recycled aggregates in concrete.

The law says: "...the use of recycled coarse aggregate is allowed according to table 2, provided that the manufactured concrete has undergone laboratory tests...".

Table 2. Technical norms of constructions – limits for recycled aggregates

Source of recycled material	Cubic compression strength [N/mm^2]	Percentage of use
Demolition of buildings (debris)	< 15	100%
Demolition of concrete or reinforced concrete elements	≤ 35	≤ 30%
	≤ 25	≤ 60%

Reuse within certified prefabrication plants	≤ 55	≤ 5%

2 RECYCLING OF C&D WASTE - STAGES OF PROCESS AND PLANT'S COMPONENTS

There are 5 stages in the recycling process of C&D waste and they are carried out in the following order:

- Coarse separation
- Crushing
- Separation of ferrous elements
- Screening
- Removal of impurity by air separation (if necessary)

During the coarse separation (performed by means of grab or shears) the debris is chopped smaller so as to go smoothly into the crusher inlet. The crushing can be also performed in the following ways:

- Squeezing;
- Impacting;
- Grinding.

To obtain a decreasingly sized product three different crushing stages are performed:

- Primary crushing;
- Secondary crushing;
- Milling.

Granulometry classes are determined during the screening operation. If necessary, impurities like wood, plastic and paper can be removed. Air separation technique is more convenient than the washing separation which is instead more expensive due to the disposal of the washing mud. The process ends with the storage of the products.

The main components of a recycling plant are:

- Crusher;
- Magnetic separator;
- Screen;
- Air classifier (if necessary)

2.1 DESCRIPTION OF A FIXED PLANT

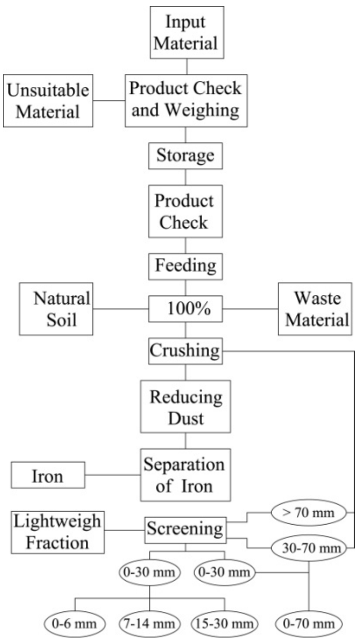

Figure 1. Flowchart of the fixed plant

The flowchart in figure 1 highlights the different stages of the material during the recycling process [Bressi, G.]. The cycle is arranged so as to avoid unsuitable material to be recycled.

Quality and quantity controls are completely automated.

The inlet material is automatically scanned out and discarded if found unsuitable to the set standards.

Three people only can fully control the plant through a video control system.

The inlet material is stored in heaps of the same kind, rolled down into the feeder through a mechanical digger in order to control the size of the inlet material. The whole process is under constant video-camera monitoring so that the rubble is checked out before entering the treatment cycle. The operator can therefore stop the feeding at any time for further checking and decide to discard unsuitable materials. The fine fraction will not be milled, therefore a first screening is carried out through a vibrating screen performs and the coarse material sent to the crusher.

An atomized water system eliminates and collects the dust after the crushing. A magnetic device then separates iron elements and stores them in a metallic box. Ceramic materials are then classed in different granulometry classes (0÷30 mm, 0÷70 mm, >70 mm this one can be crushed once again) thanks to a vibrating screen.

The vibrating screen also separates plastic from wood and paper elements and puts them into a special box.

The 30÷70mm fraction can be either stored or re-sent to the crushing. At the end of the process the different fractions are stored in heaps by a spinning device which minimizes the dust generated during the fall. Another conveyor belt can feed a further screening station which produces 0÷6mm, 6÷15mm and 15÷30mm fractions.

These granulometry classes are then further purified from impurities that are stored in special boxes.

2.2 DESCRIPTION OF MOBILE PLANTS

The mobile plants are mobile or semi-mobile machines sized for the road transport.

These machines are less expensive and easy to handle than the fixed ones, even though less efficient [Quattrone, M. & Basilico, V. 2005].

It is possible to use them inside the demolition site thus avoiding excessive handling of the debris and considerably reducing the cost of transport.

A mobile plant for C&DW recycling is made of:

- a crusher with a magnetic separator in the outlet
- a vibrating screen for the granulometry classification.

These machines are positioned next to each other to make up a recycling station (see figure 2). The crusher and the screen are usually separated.

Nowadays, it is possible to find a single machine with crusher, magnetic separator and screen (see figure 3).

Figure 2. Mobile plant composed by a crusher and a vibrating screen

Figure 3. Mobile plant composed by a single machine with crusher, magnetic separator and vibrating screen

2.3 ECONOMIC FEASIBILITY

The economic feasibility of a recycling station (fixed or mobile) depends on different factors.

This study does not consider the following factors:

- choice of the plant site;
- accessibility and availability of suitable areas;
- analysis of the building activity;
- competitors.

However, the study draws out some lines to invest in a recycling plant.

For either fixed and mobile plants, the following hypothesis can be followed:

- The price of the recycling aggregate is 80% the price of the related natural one;
- The fee to dump the rubble inside the recycling station is 85% the municipal dump fee;
- The plants produce 50% fine aggregate and 50% coarse aggregate, hence the average price of recycled aggregate is:

$$P_{av,rec} = 0.8 \times P_{av,nat} = 0.8 \times (0.5 \times P_{fine,aggr} + 0.5 \times P_{coarse,aggr}) = 9.00 \text{ €/t (euros per ton)}$$

- Based on the surveys carried out in different plants, the average quantity of iron scrap is 0.1% the quantity of produced aggregates. It shall be sold at 115 €/t.

For both plants, the net present value (NPV), the profitably index (PI) and the payback period (PP) will be calculated.

2.3.1 ECONOMIC FEASIBILITY – FIXED PLANT

Outlays and proceeds [Brugger, G.]are calculated considering the number of inhabitants N to get to the breakeven point (the minimum number of people needed to have equal proceeds and outlays).

The yearly production of C&DW is about 0.7 t/inhab. (tonnes per person). The output materials, after the recycling treatment, are as follows [Bressi, G. & Puia, P.]:

- $0.693 \times N$ t/year (99%) aggregates to sell in the market;
- 6.93×10^{-4} t/year (0.1%) iron elements to sell at the steelyard;
- 7.00×10^{-4} t/year (0.1%) impurities to be disposed of in landfill site;
- 5.60×10^{-3} t/year (0.8%) aggregates unsuitable for commercial use

The breakeven point is equal to 49121 inhabitants (see figure 4). Figure 5 shows the non-discounted cash flow; table 3 shows calculated indicators under the following hypotheses:

- Hp 1: the number of inhabitants is twice N (2 x N);
- Hp 2: the number of inhabitants is three times N (3 x N).

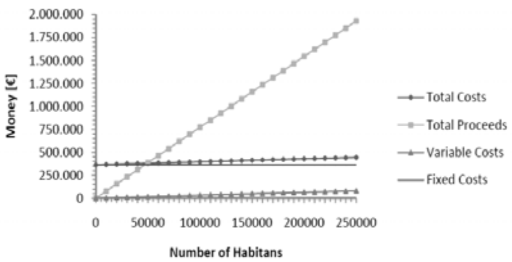

Figure 4. Costs and proceeds to determine the breakeven point

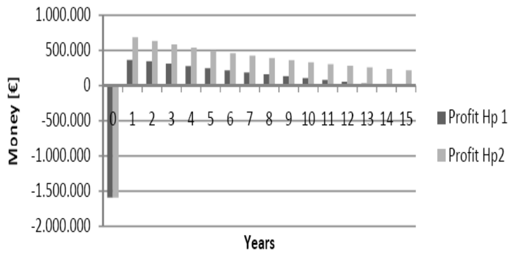

Figure 5. Not discounted cash flows

Table 3. Indicators for fixed plant

	Hypothesis 1	Hypothesis 2
Net Present Value	310.334,14	4.587.917,00
Profitably Index	0,984	1,7
Payback Period	86 months	30 months

Discount rate equal 6% for NPV, PI outlay and PP; discount rate for PI proceeds equal 8%

2.3.2 ECONOMIC FEASIBILITY – MOBILE PLANTS

Investigated mobile plants are shown in the table below.

Table 4. Characteristics of machineries

Plant	Machineries	Average Price [€]
Mobile plant A	Jaw crusher with magnetic separator - weight 30 t Vibrating screen – weight 22 t	420000
Mobile plant B	Double toothed shafts crusher with magnetic separator and vibrating screen – weight 36 t	350000

The following working hypotheses are valid:

- The capacity of the plant is 70% the maximum capacity;
- The value loss is 8% per year calculated with decreasing quotas method;
- The plant works 500 hours per year;
- The capacity of the plant decreases 4% yearly;
- Every machine is operated by one worker (labour cost is 50 € per hour per person).

Figure 6 shows the non-discounted cash flow; indicators are shown in table 5.

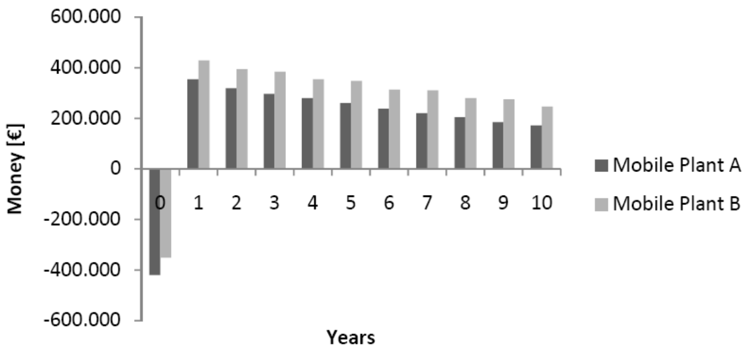

figure 6. Graph of non-discounted cash flows for two types of mobile plants

Table 5. Indicators for mobile plants

	Mobile plant A	Mobile plant B
Net Present Value	1.509.455,55	2.168.732,35
Profitably Index	1,994	3,008
Payback Period	16 months	11 months

Discount rate equal 6% for NPV, PI outlay and PP; discount rate for PI proceeds equal 7,2%

3. PRESENTATION OF STUDIES ON DEMOLITION MODES

Much interest has been lately shown towards the inert fraction (which is about 80% the total C&D waste) to be recycled in the building and civil works. All existing plants (used for collection, recycling and disposal) of metal scraps and lightweight discarded fraction can be used to treat the inert fraction.

To show pros and contras of C&D waste reclamation and reuse, the case study of an abandoned industrial area's renewal, North of Milan, is herein investigated. Prior the construction of new buildings, the old industrial structure must be dismantled. Different hypotheses about the reclamation and recycling of the debris have been formulated along with economic assessments and cost analysis.

There are several warehouses in the area: the old ones, dating back to early XIX century, are disused; the others, built in the 1960s and the 1970s, are still in good conditions.

The area is about 22800 m^2 and the total built volume is 173300 m^3. There are fifteen industrial buildings with a steel structure, lightweight roof (saw-tooth roof and saw-tooth with skylights) and external steel studwalls clad in bricks. Some sheet metal roofing material is used in the upper part of some under-roof external walls.

An inspection has to be performed and records of all the collected data have to be kept in a registry: materials, quantities, classification of elements and different recycling or reclamation methods.

This case study first analyzes how the buildings are knocked down and secondly how the materials are separated.

Economic assessments have been carried out. Costs and proceeds have been compared under the following hypotheses:

A. Building demolition and waste disposal;
B. Building demolition and C&D waste reclamation/recycling.

Table 6. Cost of demolition and disposal of all the waste produced in the hypothesis of their disposal in authorized landfill sites

Cost of demolition		1˙096˙468,00 €
Cost of asbestos-cement slabs disposal		186˙201,60 €
Cost of non-reusable material disposal		5˙167,08 €
Cement, brick debris cod.C.E.R. 17.01.07	57416,56 €	
Concrete - C.E.R. 17.01.07	10622,45 €	
Wood - C.E.R. 17.02.01	8080,45 €	
Plastic - C.E.R. 17.02.03	6572,78 €	
Iron and steel - C.E.R. 17.04.05	-123488,65 €	
Sandwich panels - C.E.R. 17.09.04	23884,00 €	
Difference between relative costs and remaining proceeds due to the disposal of the material products		-16˙912,21 €
	Total	1˙270˙924,47 €

Table 7. Cost of demolition and disposal of all the waste produced in the hypothesis of their disposal to dedicated storage and reclamation sites

Cost of demolition		1˙096˙468,00 €
Cost of asbestos-cement slabs disposal		186˙201,60 €
Cost of removal of some elements		51˙109,52 €
Cost of non-reusable material disposal		5˙167,08 €
Cement, brick debris cod.C.E.R. 17.01.07	-14835,00 €	
Concrete - C.E.R. 17.01.07	-9044,41 €	
Wood - C.E.R. 17.02.01	4150,80 €	
Plastic - C.E.R. 17.02.03	6148,96 €	
Iron and steel (first rate) - C.E.R. 17.04.05	-223142,18 €	
Iron and steel (second rate) – C.E.R. 17.04.05	-73431,16 €	
Sandwich panels - C.E.R. 17.09.04	12811,00 €	
Difference between relative costs and remaining revenues due to the recovery of the material products		-297˙342,37 €
	Total	1˙041˙603,83 €

Thanks to waste reclamation and recycling, 18% of the demolition costs can be cut off.

Disposal and reclamation costs for non-metallic fractions are outlined in table 6. The following operational hypotheses have been considered:

A. All waste are disposed of in authorized landfill sites;
B. All waste are recycled in specific plants;
C. All waste are recycled in specific plants but while inert fractions are crushed in demolition sites.

The metallic fraction is not included because it is always a proceeds.

Table 8. Comparison among the three working hypotheses

	Hp. A	Hp. B	Hp. C
Cost of non-reclaimable material dispos-al	5˙167,08	5˙167,08	5˙167,08
Cost disposal/reclaimed scraps	57˙416,56	57˙416,56	-14˙835,46
Cost disposal/reclaimed concrete	10˙622,45	10˙622,45	-9˙044,41
Cost disposal/reclaimed wood	8˙080,45	4˙150,80	4˙150,80
Cost disposal/reclaimed plastics	6˙572,78	6˙148,96	6˙148,96
Cost disposal/reclaimed sandwich panels	23˙884,19	12˙811,08	12˙811,08
total	111˙743,52	96˙316,94	4˙398,05
		-13,81%	-96,06%

Table 8 shows the cost differences in the different hypotheses. Hypothesis C allows 96% cost reduction out of the overall demolition and disposal costs than the first hypothesis.

4. CONCLUSION

This study confirms that building demolition and waste reclamation in specific plants provide high quality reclaimed materials that can be efficiently re-used.

Economic assessments show that a careful management of C&D waste can determine economic and environmental advantages.

This is true especially when debris is crushed inside demolition sites and reused in place. In a financial perspective, studies on mobile plants confirm they are sustainable in most respects.

Furthermore, mobile plants can be calibrated to be fuelled with bio-fuel.

Fixed plants, instead, are profitable when recycling and quarry's activity are complementary.

The use of machineries and special techniques for demolition and waste reclamation can reduce the environmental degradation and the depletion of raw materials.

5. REFERENCES

Ammendola, G. 2005. *Waste management. Legal requirements, ban and sanctions (in Italian)*. Rimini: Maggioli (ed.).

Brugger, G. 1979. *Industrial indvestments (in Italian)*. Milano: Giuffrè (ed.).

Clarelli, S. 2000. *Industrial estimating handbook (in Italian)*. Milano: Il Sole 24 Ore (ed.).

Bressi, G. 2005. Inert wastes: new opportunity for recycling from official statement 5205/2005 (in Italian). *Ambiente & Sicurezza*. Milano: Il Sole 24 Ore (ed.).

Bressi, G. & Puia, P 2000. Capital investment in recycled aggregate field: some appraisals (in Italian). *Recycled aggregates: logistic features and environmental problems in economical evaluation of their use; Proc. national symp. , Magenta (MI), 30 November 2000.*

Corvino, D. 2000. Technic and economic feasibility for the construction of a re cycling plant in Ferrara (in Italian). *Edilizia e Territorio* (n° 8): 17-21.

Pagani, L 2006. Suitable management of a recycling plant (in Italian). *Aggregati riciclati: un prodotto di qualità; Proc. National symp. , Rimini, 9 November 2006.*

Quattrone, M. & Basilico, V. 2005. Fixed or mobile recycling plants (in Italian). *Recycling demolizioni & riciclaggio* (n° 4, luglio): 97-102.

Quattrone, M. & Basilico, V. 2006. Raw materials … Second raw materials (in Italian). *Modulo* (n° 326, novembre): 1136-1141.

Be Aware: Built environment action on waste awareness and resource efficiency

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BRE; Malcolm Sutherland, Loughborough University UK

ABSTRACT:
The aim of this project is to reduce waste and resource use across the whole life cycle of any given construction product. The project objectives include researching the viability of modifying product design, manufacture, packaging/distribution, application, maintenance and end of life management to maximise resource efficiency. This integrated approach to considering the whole life cycle of construction products will be enhanced by conducting pan-industrial waste exchange analysis, characterisation, testing and evaluation providing opportunities for knowledge transfer. The project will model scenarios for improving resource use throughout the whole life cycle by re-engineering processes. Project web site: www.beaware,org.uk.

1 INTRODUCTION

Construction, demolition and refurbishment accounts for around 100 million tonnes of waste in the UK each year. About half of this waste is recycled, from the demolition sector and parts of the construction sector. Around 380 million tonnes of resources are also consumed by the construction industry each year, suggesting that greater scope for waste reduction, reuse and recycling exists.

Construction and demolition waste (including asbestos) is the largest component of hazardous waste in England and Wales, constituting 32%, nearly 1.7 million tonnes. Nearly all of this goes to landfill, but although arisings increased sharply in 2004 as developers sought to beat the co-disposal ban, the trend is downwards.

2 PROJECT OVERVIEW

The Department for Trade and Industry funded project is called BE AWARE – Built Environment Action on Waste Awareness and Resource Efficiency. This project aims to help construction product manufacturers to make more efficient use of materials and processes by investigating their products' design, manufacture, installation, use and eventual disposal. There are 2 main workstreams:

- supply chain resource efficiency
- cross sector recycling opportunities

BE AWARE is looking at the wastes created at each stage of a product's life cycle in order to find other uses for them.

The 30-month project is being undertaken by an industry consortium led by the Construction Products Association, and is managed by BRE. Others involved in developing, manufacturing, using or disposing of construction product are involved with the project.

BE AWARE will look in detail at around 40 products to see whether waste can be reduced and resource efficiency improved. BRE believes that the research will show that the project's approach could bring industry savings of up to 25%.

Direct help for organisations engaged in construction product design, manufacture, installation, use and end-of-life, is possible by becoming involved in the BE AWARE project,

The project will create publicly available guidance and case studies to illustrate how adopting efficient practices in product design and manufacture can help. There will also be a series of workshops during the project to discuss findings and invite further input.

The BE AWARE project's industry consortium is led by the Construction Products Association, which represent the construction product manufacturing sector. Other participating associations/groups with manufacturing members include plastics (British Plastics Federation), concrete (British Precast Concrete Federation), composites (NetComposites) and wood (Wood Panel Industry Federation, British Woodworking Association).

Modular buildings are represented by the Modular & Portable Building Association. Key clients/advisors include Charnwood Borough Council and National House Builders Council. Biffa Waste Services and the National Federation of Demolition Contractors provide guidance on the end of life stages.

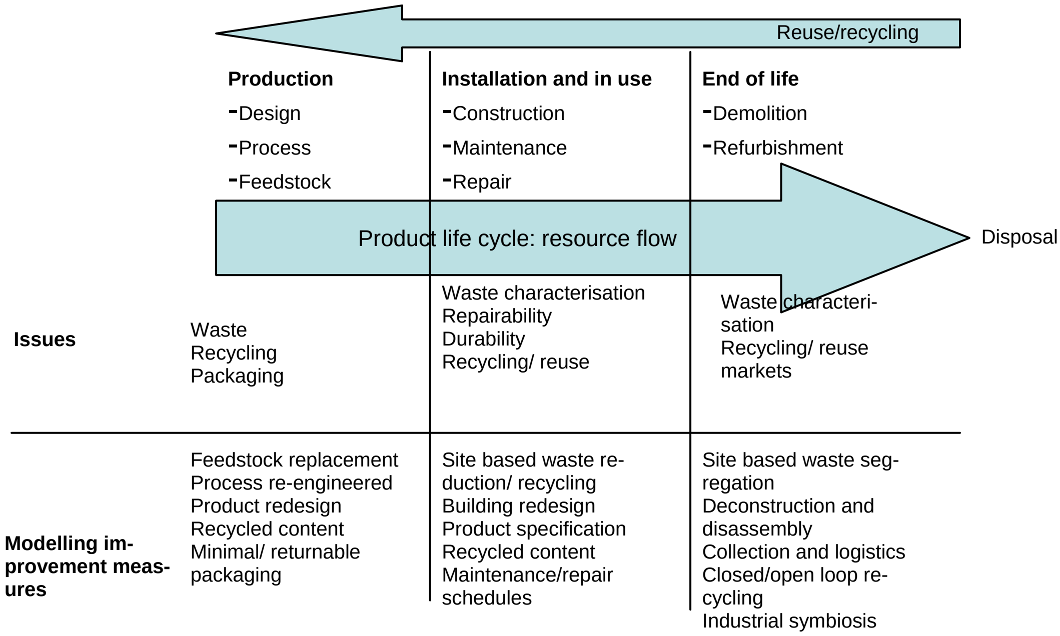
Partners from the packaging (Packaging and Industrial Film Association), agriculture (Agrifibre Technologies Ltd) and solid timber (UK Forest Products Association) provide opportunities for pan-industrial knowledge transfer. Loughborough University bring their technical expertise with regards to cross-cutting industry waste mapping. Associated parties include Resource Efficiency Knowledge Transfer Network and National Industrial Symbiosis Programme (NISP). BRE provides overall project management from its Centre for Resource Efficiency.

3 OBJECTIVES

This project will reduce waste and resource use across the whole lifecycle of any given product. Research objectives include:
a) Mapping a product's resource profile and highlighting where improved resource use is possible through reduction, reuse, recycling, recovery and end of life recyclability. These include design (e.g. primary feedstock substitution with recycled materials), manufacturing process (e.g. cost v. benefit of changing practices), packaging (e.g. design for minimal packing) and end of life considerations (e.g. maintenance, recyclability/ retrieval arrangements),
b) Simulating reduced resource use through the whole life cycle by modelling a re-engineering of processes and changing, for example, the design, distribution, packaging and end of life recovery options,
c) Creating a pan-industrial waste exchange process through researching waste mapping, characterisation, testing and evaluation.
d) Marketing and disseminating the results to wider industrial audiences.

Figure 1: Diagram explaining project scope

Reducing waste through integrated product design and manufacture



3 BENEFITS

Lifecycles will be modelled rather than individual industry interests. This involves combining perspectives and data from over 50 companies to develop the results of the project; the manufacture around 40 products will be improved as a consequence. Results will reveal the extent to which input resources can be minimised and, through tests, characterisation and optimisation of waste materials, identify what can be put back into construction and other product manufacture.

Specific outputs will be full accounts of resource flows throughout a product lifecycle, contrasted against alternative methods of manufacture, installation and end of life treatments to create more sustainable manufacturing practices. Generic industry guidance will promote wide scale uptake of the approach/findings. The waste characterisation process effectively matches supply and demand in materials output from all stages of product lifecycles. Results will also optimise resource use between different industry sectors. Commercially, manufacturers need to be more resource efficient due to rising disposal costs; corporate social responsibility and preparing for legislative change. e.g. extension of the EU Eco-design Directive.

Companies participating in the project will be provided with the necessary knowledge to change processes, design and feedstock to reduce waste and save money. Obviously, the whole construction products sector will not adopt the research findings, but the key trade bodies are committed to the project and the requirement to disseminate the results/ encourage uptake. Additional exploitation derives from where product redesign would reduce environmental impact. This will inform policy makers, e.g. the Market Transformation Programme. Wider exploitation and dissemination are inextricably linked; the launch, web presence, seminars, press releases, guidance documents, industry workshops, advisory groups and task groups will all serve to engage potential users of the results and ensure the outputs are fit for purpose.

4 PROGRESS TO DATE

Supply chain resource efficiency

The objective is to reduce resource use across the supply chain withour increasing other impacts. This involves finding out detailed data on resource use for energy, water and materials at several stages, including manufacture, installation and demolition. A questionnaire to capture this data has been developed, along with a process for quantifying the impact reduction for any interventions or changes to the process.

Figure 2-4 shows how resource impacts can be broken down for a composite product.

Figure 2: Overall impact

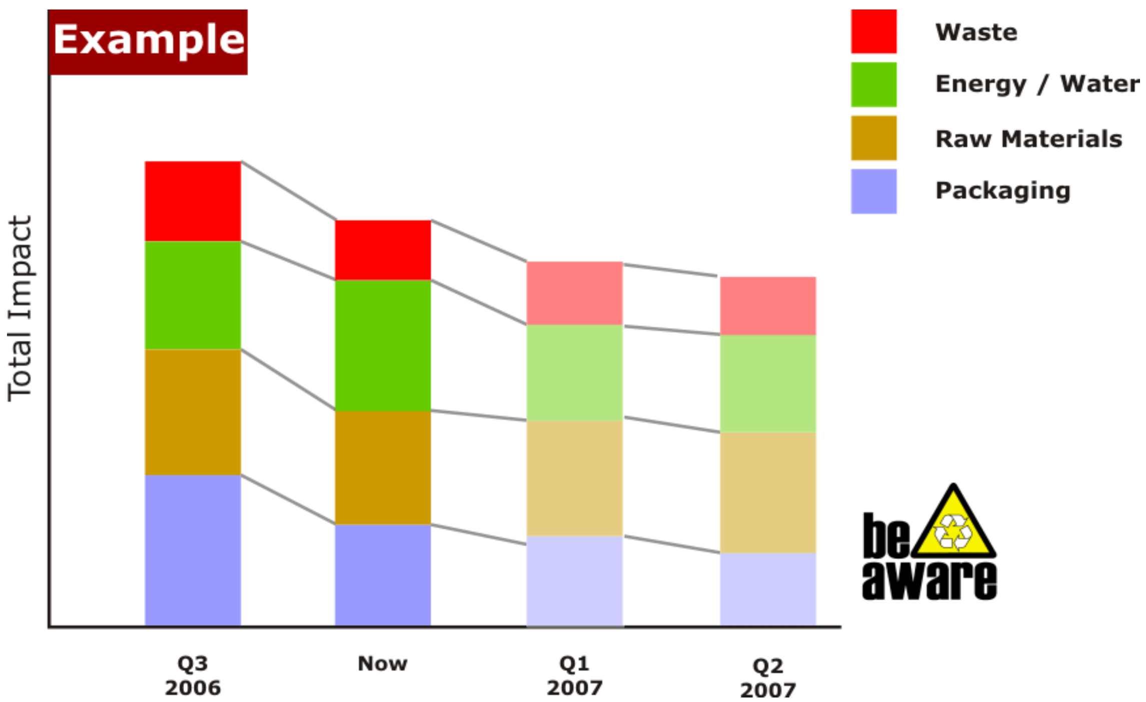


Figure 3 Impact of raw materials

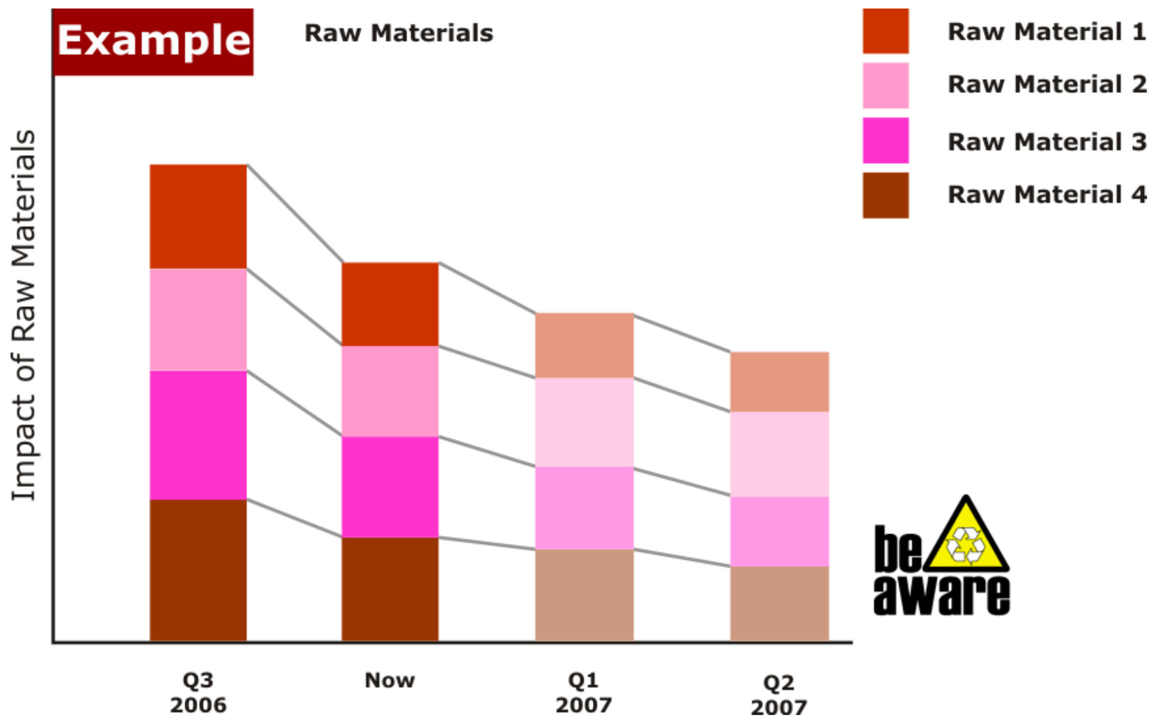
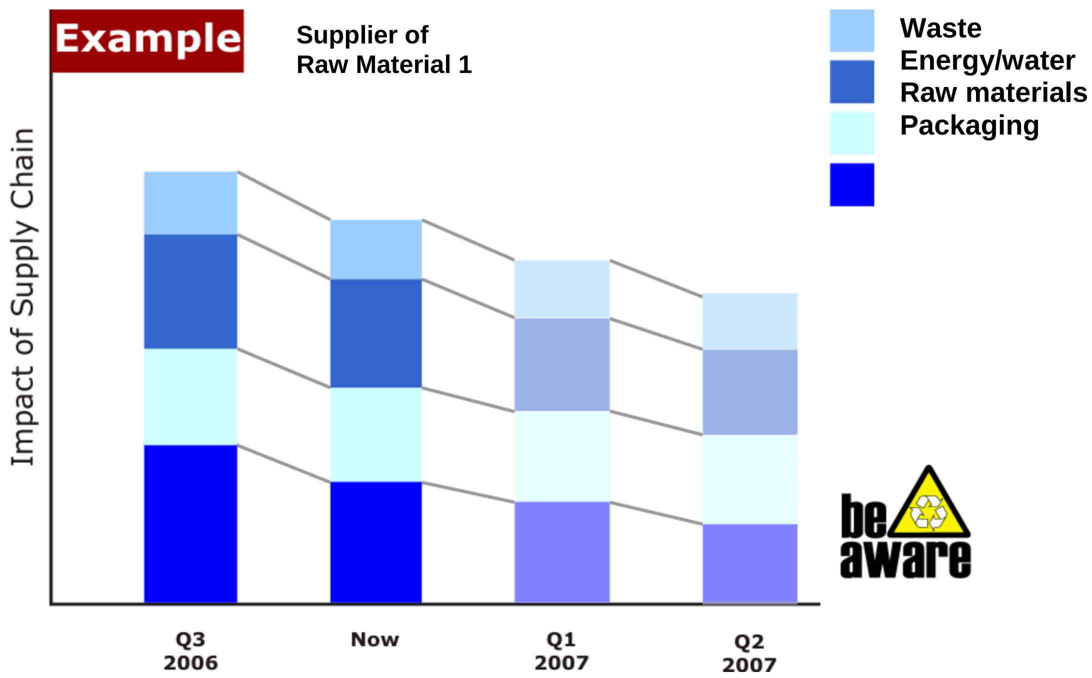


Figure 4 Impact of raw material 1



By having the ability to see each impact of each raw material, it is possible to model the effect of changes in feedstock and suppliers upstream of the product manufacturers. This aspect of the project is continuing to be developed with a series of construction products and their supply chain.

Cross sector recycling opportunities

A waste characterisation literature review was conducted to examine existing waste characteristics, approaches, technologies and methodologies. The main findings were as follows:

Waste characteristics approaches
Waste materials are classified into groups of similar items, such as plastics, wood and bricks. Waste streams and materials are quantified through onsite observation, sampling, interviews or questionnaires. Waste materials are generally studied for their chemical or physical composition, in order to identify and hazardous chemicals or contamination, or to assess their suitability for recycling. The viability of recycling a waste material is affected by financial costs, including haulage, capital costs (e.g. purchase of equipment), market value and environmental taxes. Finally, the potential for recycling a waste material is also governed by its performance related properties, including durability, purity, safety and physical stability.

Waste characterisation technologies
Waste characterisation depends on the use of technical tools, including databases, models and laboratory equipment. Computer databases can be used to assemble and organise extensive data which can be altered and updated. Computer modelling can be used to map complex processes such as the transfer of materials and wastes within an industry sector in order to predict different waste management scenarios. Assessment of waste materials can involve the analysis of hazardous chemicals in samples and comparing results against environmental legislation.

Waste characterisation methodologies
Waste characterisation methodologies including sampling, analytical techniques and the marketing of recycled products. Sampling involves collecting waste samples, or gathering information through interviews and questionnaires. The accuracy of data collected through sampling will be limited by time, cost and accessibility to information or the materials. Possible contamination of laboratory equipment and the precision of the data produced are the key issues to consider when analysing waste materials. Marketing a recycled material includes surveying customer's opinions, establishing a market value, assessing the level of competition in the market and examining all the costs involved in producing and selling the material.

Industry workshops
Be Aware recently organised and held the project's second workshop on cross sector recycling opportunities. Attended by delegates from a range of sectors in the construction industry, this successful workshop set out to identify the factors which currently inhibit waste recycling and reuse, and to subsequently propose solutions for addressing such limiting factors.

Representatives of construction product manufacturing companies, demolition/refurbishment contractors and consultancies worked together to consider the limiting factors within both an economic and a material performance-based context.

Waste materials considered during the workshop included by-products which are currently being recycled or reused to a certain extent, as well as residues being sent to landfill.

The data collected during the workshop will be used to develop a methodology for selecting a number of waste materials, which in turn will be tested further in the laboratory in order to optimise their recycling potential.

5 INTERIM CONCLUSIONS

The companies working with the Be Aware project are already seeing benefits of involvement through identifying quick wins in terms of waste reduction and recycling actions.

A stronger linkage across the supply chain in terms of defining the resource and waste issues sends a powerful message. Everyone involved with the construction supply chain has some form of accountability and potential to influence resource use outside of their immediate control.

There are still technical issues for key wastestreams and recycling opportunities that need to be set alongside the financial viability and technical performance requirements of the construction products sector. These form the basis of a cost benefit evaluation that will determine if recommendations are able to be implemented.

The need and means for sustainable use of wood in the Tanzanian construction industry

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ABSTRACT: Pronounced increase in construction activities in Tanzania has a corresponding utilization of wood products. This adds to the already aggravated situation by wood harvest for fuel; manufacturing and forest clearance for agricultural purposes. In most cases exploitation of wood is done to fulfil the immediate social and economic gains while paying minimum attention to the extended environmental ramifications. Among other aspects, the industry is characterized by use of wood harvested from sensitive environments like mangrove forests, for temporary structures such as scaffolds and formworks. On the other hand, high quality timber is used for relatively undeserving joinery works. Worse still, when the temporary structures are demolished the wood end up in cooking stoves as fuel while they could be reused or recycled for construction purposes. This paper presents the observed shortcomings and highlights the applicable mitigations that are being explored in the ongoing research.

1 INTRODUCTION

The term wood is used in this paper to connote both lumber and timber, as tree products used in construction works. The relative abundance and unique characteristics of wood, has made it a momentous construction material throughout recorded human history. Today, wood is used in a multitude of applications including construction of buildings, bridges, railroad crossties, boats and ships, power and communication posts, furniture-making and sculpting (Linstrom & Schwartz 2007, Milton 2002 & FPL 1999).

The need for sustainable utilisation of wood (i.e. meeting the wood needs of the present without compromising the ability of future generations to meet their own wood needs), follows the observed increase in construction activities in Tanzania (Mufuruki et al. 2007) with a corresponding utilization of wood products. This adds to the already aggravated deforestation due to wood harvest for fuel; manufacturing and forest clearance for agricultural purposes. While 8753 tree species are listed as threatened globally, logging alone is threatening 1000 of them (Magin 2001). Consequently, there is deterioration of the use and non-use values of forest (UNEP 2002, MNRT 2001& Shechambo et al. 2001). In Tanzania for instance, wood from sensitive environments like mangrove forests, is used for temporary structures such as scaffolds and formworks (Fig. 2) which are used once or twice then become firewood.

The information presented inhere comes from literature and field survey conducted as part of the on going research. The field survey and observations were conducted to identify and characterize the wooden materials used and waste generated at construction and demolition sites. Twenty two building construction sites were identified from Ilala, Kinondoni and Temeke municipalities (Table 2) in Dar es Salaam City, Tanzania. A checklist was used to record among other aspects, the type and amount of wood used for temporary structures namely, scaffolds and formworks. The findings led to recommending use of scaffolds and formworks made of steel. Furthermore, reusing and recycling of wood where technology, economics and healthy aspects are in favour of the process (Magin 2001), may contribute to sustainable use of wood.

2 WOOD AS CONSTRUCTION MATERIALS

The Wood is a heterogeneous, hygroscopic, cellular and anisotropic material. Its dry weight composition constitutes 50% cellulose fibres; 15% to 25% of hemicellulose held together by 15% to 30% of lignin (Milton 2002 & FPL 1999). The fibrous nature of wood strongly influences how it is used (FPL 1999). Literature (Milton 2002 & FPL 1999) gives detailed mechanical, structural, functional and aesthetic properties of wood that facilitate its workability as construction material. Nevertheless, wood is venerable to biological deterioration and fire. These problems may be mitigated by application of preservative and fire retardant treatment respectively. As such, wood can be highly durable if properly protected or treated (Milton 2002).

3 THE NEED FOR SUSTAINABLE USE OF WOOD

Wood comes from the forests which on a global scale are estimated to occupy about 30% of the land area (FAO 2005, Katila & Simula 2005). The world has about 3.9 billion hectares of forests, of which 95% are natural and 5% are plantations. The largest proportion of the world's forests is in the tropical zone (47%), followed by the boreal (33%), temperate (11%) and subtropical (9%) zones (Katila & Simula 2005). In Tanzania, about 38% of the Country's 886,000 km^2 total land area is covered by forests and woodlands (Table 1) that provide for unique wildlife habitat, natural ecosystems and biological diversity and water catchments.

Table1. Wood-related land uses in Tanzania as reported by various authors in different years

Wood-related land uses	Area (10^6 ha)						
	Flinkman (2004)	Wang, et al. (2003)	Shechambo et al. (2001)	Yahya, (2000)	MNRT (2000)	FBD (1999)	Semesi (1992)
Forests	1.40	-	1. 141	1.4 00	-	2.72	-
Mangrove	0.08	0.108	0.115	0.115	0.115	-	0.116
Woodlands	42.9	-	32.299	42. 891	-	37.44	-

Tanzania is facing unprecedented urban growth and commercialisation as is the case for many countries in the sub-Saharan region. This in turn, exerts enormous pressure on natural resources including forest products such as wood (Shayo 2006, UNEP 2002, MNRT 2001 & Shechambo et al. 2001). The situation is aggravated by the skewed market preference on few indigenous tree species. This leads to over exploitation of these trees in natural forests. Indigenous hardwoods from the natural forest account for about 300 000m^3/year round wood whereas plantations contribute about 600,000 m^3/year round wood (Shayo 2006).

3.1 *The value of Tanzania forestry resources*

The use values (UV) of the forest resources (Eq.1) have a crucial role in the contribution towards poverty eradication for the rural poor, economic development, biodiversity and environmental conservation (MNRT 2001). UNEP (2002) and Shechambo et al. (2001) detailed the use and non-use values of the forestry resources, a discussion below makes use of some of their concepts.

3.1.1 *Use values (UV) of the forests*

Equation 1 gives an expression for the use value of forests:

$$UV = DUV + IUV + OV \tag{1}$$

Where: DUV = Direct use value, meaning what humans extract or consume directly from the forest for commercial and industrial market forest goods and services i.e. fuel wood, timber, pulpwood, poles, fruits, animals, fodder and food, medicines, recreation etc.),

IUV = Indirect use value are the benefits from ecological services, such as flood control, storm protection, carbon sequestration, climate amelioration etc;
OV = Option value regarded as a premium placed on maintaining resources for future possible direct and indirect uses, some of which may not be known now e.g. cure for deadly diseases such as AIDS.

3.1.2 *Non use value (NUV) of the forests*

The non-use value of forests includes both existence and bequest values as illustrated by Equation 2.

$$NUV = XV + BV \tag{2}$$

Where: XV= Existence value is the value that human beings attach to the fact that they would like to have the forest resource exist for its intrinsic value, and their destruction is a bad thing.
BV = Bequest value, this is the value that future generation may also have the opportunity to enjoy such forest resource in their own right.

3.1.3 *Total value (TV) of the forests resources*

Summing up Equations 1 and 2 gives Equation 3, which is the expression for the total value of forestry resources.

$$TV = UV + NUV = [(DUV + IUV + OV)] + [(XV + BV)] \tag{3}$$

3.2 *Deforestation due to human interventions and its ramifications*

The Tanzanian forests are depleted at a rate of between 130,000 and 500,000 ha per annum, which results from heavy pressure from agricultural expansion, livestock grazing, wild fires, over-exploitation and unsustainable utilization of wood resources and other human activities (MNRT 2001). According to FAO (2005), Tanzania lost 412267 ha equivalent to 14.9 % of forest area in fifteen years from 1990 to 2005. Measuring the total rate of habitat conversion (defined as change in forest area plus change in woodland area minus net plantation expansion) for the period 1990-2005, Tanzania is estimated to have lost 37.4% of its forest and woodland habitat (FAO 2005).

A significant change in wood consumption is attributed to the liberalization of forestry sector and implementation of the National Forestry Policy in Tanzania since 1998. During that period the three key wood consuming activities namely fuelwood, manufacturing and construction, recorded change in wood consumption of 900,000m^3; 551,838m^3; and 459,000m^3 giving an estimated ratio of 2:1.2:1 respectively (UNEP, 2002).

3.3 *Wood consumption and wastage in construction of new buildings*

The results from the investigated twenty one construction sites indicated that 73% of the sites used wooden scaffolds and formworks. The remaining 27% used both timber and steel for the two temporary structures (Table 2). It was observed that even the site that used the majority of steel, sawn timber was still used for slab support plates, stages and ladders (Figure 1). This is an indication of continued reliance on timber for temporary structure at construction sites.

Table 2. Usage of steel and timber for making formworks and scaffolds at observed building construction sites in Dar es Salaam City, Tanzania

Municipality	Number of construction sites	Scaffolds			Formwork		
		Timber	Steel	Timber and Steel	Timber	Steel	Timber and Steel
Ilala	10	6	0	4	6	0	4
Kinondoni	7	5	0	2	5	0	2
Temeke	5	5	0	0	5	0	0
Total	*22*	*16*	*0*	*6*	*16*	*0*	*6*
Percent	*100*	*73*	*0*	*27*	*73*	*0*	*27*

(Data from field survey and observation)

The data collected from the sixteen sites that used wood for scaffolds and formworks (Table 3), lead to the establishment that the sites used a combined total of 39179 wooden poles. On average, each of the structures used 7 wooden poles per square meter of floor area. Additionally, the estimated average of used sawn softwood timber amounted to four metric tonnes per floor area of 235 m^2, giving a total of average of 92 tonnes for the sixteen observed sites.

Table 3. Number of wooden poles used as scaffolds at observed building construction sites in Dar es Salaam, Tanzania

Site Code	Number of floors	Number of poles per floor	Total number of poles	Floor area (m^2)	Average number of poles per m^2
I_1	2	713	1426	108	7
I_2	1	1920	1920	300	6
I_3	2	324	648	36	9
I_4	2	1220	2440	192	6
I_5	2	1457	2914	216	7
I_6	1	800	800	108	8
K_1	2	3055	6110	450	7
K_2	1	2091	4182	320	7
K_3	1	1767	1767	252	7
K_4	2	1930	3860	288	7
K_5	1	3250	3250	396	8
T_1	1	2170	2170	300	7
T_2	2	2015	4030	264	8
T_3	1	1240	1240	180	7
T_4	1	1302	1302	192	7
T_5	1	1120	1120	160	7
Total	23		39179	3762	Average 7

(Data from field survey and observation)

While it may not look as a big deal to use a total of 39179 poles in sixteen buildings, but the fact that they were used temporarily raise concern because as observed in this study most the wood is used once or twice. Thereafter the old wood is used as firewood, in most cases sold to food vendors and fish mongers who use it as fuel for cooking food and frying fish at the Kivukoni fish market, in the City. This implies that the contractor will purchase new poles and sawn timber for the next project.

Even more alarming is the fact that each of the wooden poles was a whole young tree by itself (Fig. 2). The amount of trees used at the sampled sites coupled with the building construction rate in Dar es Salaam, may be extrapolated to predict other scenarios such as deforestation rate and the associated ramifications. This is one of the goals of the ongoing research.

Figure 1. One of the six sites (Table 1) where both wood and steel were used for temporary formwork and scaffolds in casting in-situ reinforced concrete in the construction of multi-storey buildings in Dar es Salaam City, Tanzania (field observation)

Figure 2. Typical wooden formwork used as temporary supporting structures in casting in-situ reinforced concrete in the construction of multi-storey buildings in Dar es Salaam City, Tanzania (field observation)

4 APPLICABLE MEANS FOR SUSTAINABLE USE OF WOOD IN CONSTRUCTION

The means for attaining sustainable use of wood in the Tanzanian construction industry include minimisation of wood used for formwork and scaffolds and embarking on reusing and recycling of construction wood products

4.1 *Minimisation of wood used for temporary structures*

As observed in Section 3.3, a lot of trees are cut only to be used once or twice for temporary structures such as form works and scaffolds. It was also observed that reusable steel formworks and scaffolds have the capacity to save the trees. However, most building contractors claim that it is financially cheaper to use wood instead of steel which require relatively high initial capital. But looking at the cost from the environmental point of view, it is appealing to incur financial cost rather that environmental costs. The former can be recovered in many ways while the latter may be irreversible for example loss of habitat and consequent species extinctions.

Even though it is out of the scope of this paper, a scientific approach to establish the line of argument would be carrying out a detailed cost benefit analysis, on one hand for investing in steel formworks and scaffolds to be used in several estimated number of projects and on the other hand, a corresponding cost benefit analysis of using wood for the same number of projects. A comparison of the two would then give a decisive choice.

The next step is to establish the mechanism to ensure that contractors opt for steel instead of wood. This would be in line with the Tanzania Construction Industry Policy (CIP), which clearly promotes application of sustainable construction practices including; application of technologies, products and practices, which are not harmful to the environment, human health and safety (MoW, 2003). One of the aspects inspected for registration or upgrading of contractors by the contractors' registration board in Tanzania, is the equipment owned by the company (CRB, 2006). As such, steel formworks and scaffolds may be included in the list of obligatory equipment prior registration of contractors.

4.2 *Reusing and recycling wooden materials*

While describing the state of the art of reusing and recycling timber in the UK, Magin, (2001), explained the constraints to increasing timber reuse and recycling. The discussion below gives the constraints that are likely to have impact in developing countries like Tanzania and the proposed applicable remedial measures:

There exist stringent building regulations and material specifications for structural and load bearing functions that are hard to meet with reused and recycled wood. The choice here is to apply reused or recycled wood to less demanding non-structural or load bearing applications.

Sporadic nature of supply of reclaimed wood does not guarantee the availability of the right material at the right time in the right place for a specific project. Establishment of centres for reclaimed and sorted wood may in one hand help in formalising the business and on the other help to make easy the search for certain wood specifications.

Demolition is often done very fast to maximise use of equipment which are in most cases hired (e.g. bulldozers) in limited short time scale. In turn limits efficiency in reclamation of materials that require more time and personnel. Deliberate and careful planning of deconstruction instead of demolition activities and if enforced by law, may facilitate reclamation and sorting of useful wood from old structures.

Contamination of materials mainly due to preservatives, glues, metals e.g. nails may limit the recycling reclaimed wood into panels, chipboard etc. Meticulous sorting by waste producers could minimise this problem.

Many of the sources of waste wood that might be appropriate for reuse or recycling are relatively small and dispersed, making the economics of waste collection by recycling companies marginal. Where business space is available, establishment of centres for storage of sorted reclaimed wood may facilitate the business.

The equipment required for wood recycling (principally a chipper) is expensive to purchase. It is therefore only viable where a large, uncontaminated, reliable supply of recyclable timber and a market for the woodchips are both assured.

Wood reuse and recycling is still in its infancy. Many companies, especially smaller businesses, are unaware of the options for waste wood apart from fuel. Public awareness of wood waste, transmitted to the timber industry via retailers, could prove an important driver in decreasing waste levels and increasing reuse and recycling

Certain types of preservatives applied to some timber, especially items for external use such as railroad crossties and telephone and power communication poles, render wood unsuitable for recycling for panel manufacture, or for burning (the preservatives generate toxic emissions when burnt). Careful sorting is needed to exclude them from the general wood waste stream, and an alternative method of disposal is needed. However, it is possible that the uninformed population in developing countries continue to use them as firewood.

4.3 *Appropriate use of natural hardwood*

Field observation and information from literature indicated skewed market preference on few indigenous hardwood tree species such as *Pterocarpus angolensis* (mninga) which is the most preferred species of timber for furniture making in Tanzania. Other hardwood species include *Afzelia quanzensis* (mkora), Brachystegia spiciformis (mtundu) and *Erythrophleum africanum* (mkarati), *Pao rosa* (msekeseke), *Swartzia fistuloides* and *Chlorophora excelsa* i.e. iroko *(mvule)* (Shayo 2006).

The use of such, high quality hardwood for otherwise cheap furniture may be translated as ignorance or as a result of cheap illegal means of obtaining the wood from protected areas, because the culprits do not pay appropriate taxes. On the other hand, the furniture made from such wood as *P. angolensis* are relatively very heavy. One way of solving this problem is raising public awareness and minimizing opportunities for illegal logging.

5 CONCLUSIONS AND THE WAY FORWARD

The need for sustainable utilisation of wood in the Tanzanian construction industry stems on the fact that the current deforestation rated at 130000 to 500000 ha per year is alarming. The ratios of 2:1.2:1 for the key wood consuming activities namely fuelwood, manufacturing and construction, indicate a significant share of the construction industry. Field observations, have demonstrated the need to minimise use of wood in formworks and scaffolds as they consume a lot of young trees and timber. Above all, the risk of loosing the use and non-use values of the forests from which the wood products are harvested, present an even stronger reason for exploring sustainable ways of utilising wood products.

The current use of wood for scaffolds and formworks can and has to be minimised by using steel materials which are reusable several folds of times as compared to wooden ones. However, a detailed cost benefit analysis (financial and environmental) is required to form the basis for making use of steel mandatory. Furthermore, reusing and recycling of wood has promising but undeveloped capacity to reduce pressure on virgin wood resources. The lack of sufficient data on wood use and waste generation, the infancy of wood recycling industry and poor public awareness are some of the key issues that need keen attention before successful sustainable use of wood in the Tanzanian construction industry can be guaranteed.

REFERENCES

Contractor's registration board -Tanzania (CRB). 2006. *Directory of registered contractors*

Flinkman Matti. 2004. Institutions and Wood Supply to Construction Wood Markets in Dar es Salaam and Mwanza: Implications for Policy and Enforcement, *Scandinavian Journal of Forest Research*, 19:4, 25 - 35

Food and Agriculture Organization of the United Nations (FAO). 2005. Global Forest Resources Assessment 2005.Progress towards sustainable forest management, *FAO Forestry Paper 147*

Forest Products Laboratory (FPL). 1999. Wood handbook-Wood as an engineering material. Gen. Tech. Rep. FPL-GTR-113. Madison, WI: U.S. *Department of Agriculture, Forest Service, Forest Products Laboratory.* 463 p.

Katila Marko and Simula Markku.2005. Sustainability impact assessment of Proposed WTO negotiations. *Final report for the forest sector study*. Savcor indufor Oy, Finland in association with Impact assessment research centre, Institute for development policy and management, University of Manchester, UK

Linstrom Amy and Schwartz Jeff. 2007. The Colour of Materials: Wood. *Internet site: http://research.the-bac.edu/color/wood/index.html* (accessed in May 2007)

Magin Georgina. 2001. An introduction to wood waste in the UK. *Fauna and Flora International, Cambridge, UK;* 40 pages

Milton, F. Thomas. 2002. The Preservation of Wood. A Self-Study Manual for Wood Treaters. *Department of Wood and Paper Science, College of Natural Resources, University of Minnesota*

Ministry of Natural Resources and Tourism (MNRT). 2001. *National forest Programme in Tanzania 2001- 2010*

Ministry of Natural Resources and Tourism (MNRT). 2000. Forestry studies in Africa –United Republic of Tanzania

Ministry of Works (MoW). 2003. Construction Industry Policy (CIP). Government printers, Dar es Salaam-Tanzania

Mufuruki Tobias, S.; van Egmond Emilia L. C. and Scheublin Frits J.M. 2007. Reusing and Recycling Construction Aggregates as Mitigation Measures to Environmental Destruction. The Case of Dar es Salaam, Tanzania (CIB2007-485). *Proceedings of the CIB World Building Congress 2007 on Construction for Development.* Cape Town, 2007

Semesi, K. Adelaida. 1992. Developing management plans for the mangrove forest reserves of mainland Tanzania. *Hydrobiologia* 247(1-3): 1-10

Shayo Hildebrand.2006. Forestry governance in limbo in Tanzania-A case study of a supply chain of the indigenous hardwood timber, timber trade and procurement code. *RICS Research paper series*, Volume 6, Number 5

Shechambo Fanuel, Salehe John and Mariki Stephen. 2001. The economic value of Tanzania's forests. *Report of a workshop held at the courtyard hotel, Dar es Salaam – Tanzania 15th august 2001. Technical report No. 3*

United Nations Environment Programme (UNEP). 2002. The forestry sector in Tanzania. *Country projects – round II – A synthesis report, New York and Geneva.*

Wang Y.; Bonynge G.; Nugranad J.; Traber M.; Ngusaru A.; Tobey J.; Hale L.; Bowen R.; Makota V. 2003. Remote Sensing of Mangrove Change along the Tanzania Coast. *Marine Geodesy*, Volume 26, Numbers 1-2, Numbers 1-2/Jan-Jun 2003, pp. 35-48(14)

Yahya Saad S.2000.Woodfuel and Change in Urban Tanzania. *SYA Associates, Nairobi, Kenya*

An experimental study on properties of mortar mixing activated Hwangtoh considering pozzolanic reaction

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ABSTRACT: The Hwangtoh(a kind of red clay or loess which is like metakaolin, we called it hwangtoh in Korea) is one of the traditional and eco-friendly construction material used as part of a wall, plastering material, and ondol (Korean under-floor heating system) with stones, hays and woods in Korean traditional style house. It has many advantages and benefits such as; high storage of heat, self-purifying ability, antibiotic ability, and emission of far infrared rays. Most of all it is an important natural material because it is a sustainable material. But, it has not been developed and used as a modern construction material until now, because of its low strength and drying shrinkage crack properties. According to the recent researches and studies, it is evaluated for natural pozzolanic material like flyash or pozzolan now. Its possibility to be used as construction material is high because its chemical and mineralogical proportions are similar with metakaolin and kaolinite. So, it shall be significant to illuminate and analyze properties of mortar mixed with the activated Hwangtoh. In this point of view, this study aims at researching and analyzing the basic physical properties of activated Hwangtoh mortar through an experiment with various activation conditions of Hwangtoh and mixing conditions of mortar: It, also, targets increasing the possibility of using Hwangtoh as a modern construction material.

1 INTRODUCTION

Even though the cement, which is the main raw material for the concrete, is the most widely used as one of the modern building materials due to its strength of good quality and workability, we should come with a counterplan because the cement is blame to threaten the environment of earth while raising problems such as air pollution, ozone depletion, global warming, etc because of CO_2, dust, and waste, which are mainly generated in the process of its production, and from the high energy consumption in producing it.

As one of Korean typical traditional building materials, Hwangtoh has been used for Ondol floor, wall and plaster work together with stones and trees. Hwangtoh is the eco-friendly material with strength such as high heat insulation, self-purification, deordorization & antimicrobial efficiency, and emission of far infrared ray healthful for human body. In addition, as a mineral belonging to Halloysite of Kaolinite family, the domestic Hawngtoh has SiO_2, Al_2O_3, Fe_2O_3 as its main ingredients. So it has the property of natural pozzolan similar with ordinary concrete admixture. Moreover, Hwangtoh generates CSH gel and CASH gel by pozzolanic reaction with $Ca(OH)_2$ which is the cement hydride by activated organic SiO_2 and Al_2O_3 in case of being plasticized in high temperature. Hwangtoh is highly estimated as a substituting material for admixture of concrete and mortar, which is the cement with very high pozzolanic reaction. Although the methods to utilize it have been studied on in diverse aspects, Hawngtoh has not been able to be developed as the modern building material because of its weakness such as cracks by the large shrinkage, low strength property. It is judged that Hwangtoh is worthwhile to use in order to reduce the cement production, environmental problem, and energy use.

In this aspect, this study aims at suggesting the possibility of using Hwangtoh as the substituting material for cement. Also, it shall be intended to accumulate data on material science and engineering of activated Hwangtoh mortar to examine the optimal activation condition, homogenization, and high efficiency through the experiment and analysis on physical property of activated Hwangtoh according to various activation conditions and mixing/curing conditions of Hwangtoh which is the natural pozzolanic material.

This study focuses on the examination on diverse activation conditions of Hwangtoh and mixing/curing conditions of mortar to induce the appropriate pozzolanic reaction of Hwangtoh through the theoretical study on cement hydration reaction and pozzolanic materials, also through the study on Hwangtoh and mechanism for pozzolanic reaction.

For the condition of Hwangtoh activation and its mixing factor applied to mortar, the activation temperature & time, fineness of Hwangtoh, its cooling method, and substitution ratio were set as variables of the entire experiment. By performing the comparative analysis on physical properties of mortar before/after hardening while focusing on the flow, dry shrinkage change, compressive strength, and micro cement hydride structure through Scanning Electronic Microscope(referring as SEM hereunder), an analysis was made on the correlation in between experimental factors considering the physical property influence coefficient. We also examined on the plan to use the optimal activated Hwangtoh mortar while examining the appropriate Hwangtoh activation condition and mortar mixing condition.

2 EXPERIMENTAL PLAN AND METHOD

2.1 *Experimental plan*

In order to analyze the correlation and physical properties of each physical property influence factor of the mortar supplemented with activated Hwangtoh, we classified six(6) series in total, and mixed mortar with physical property influence factors of mortar in different level for each series. Table 1, 2 indicate the mixing property and experiment purpose of each series, and total mixing plan of mortar.

Series I is the standard mortar which is not added with Hwangtoh. The standard sand was used as its fine aggregate. Its water-cement ratio was mixed at three(3) different levels of 50%, 60%, and 70%. Series Ⅱ was intended to understand the influence according to the activation temperature of Hwangtoh when mixing mortar: its water-cement ratio was 60%. The substitution ratio of Hwangtoh was 15%, and the fineness of used Hwangtoh was 13㎛ while we mixed 12 different levels of soils which had been activated for one(1) hour respectively with the interval of 50℃ by 600~1100℃. Series Ⅲ was intended to understand the characteristics of mortar according to the activation time by fineness of Hwangtoh. Its water-cement ratio was 60%. As for the Hwangtoh condition, the substitution ratio was 15% and its fineness was at three3) level of 43㎛, 13㎛, 8㎛, and its activation time was divided into 1 hour, 2 hours, 3 hours respectively.

Table 1, Mixing property and experimental purpose of each series

<table>
<tr><th></th><th>Mixing Characteristic</th><th>Purpose</th><th>Test item</th></tr>
<tr><td>Ⅰ</td><td>Standard sand, W/C=50,60,70%</td><td>Properties on the standard mortar that do not mix Hwangtoh</td><td rowspan="4">-flow
-workability
-drying shrinkage
(3, 7, 14, 28day)
-compressive strength
(3, 7, 28day)
-microstructure analysis
(SEM analysis-28day)</td></tr>
<tr><td>Ⅱ</td><td>Hwangtoh activated temperature
20℃, 600~1100℃</td><td>Properties on the mortar according to curing type and Hwangtoh activated temperture</td></tr>
<tr><td>Ⅲ</td><td>Hwangtoh size(diameter)
43, 13, 8㎛,
Activated time 1, 2, 3Hour</td><td>Properties on the mortar according to Hwangtoh activated time</td></tr>
<tr><td>Ⅳ</td><td>Substitution ratio of Hwangtoh
5,10,15,20,25%
cooling type(slow, fast)</td><td>Properties on the mortar according to Hwangtoh Substitution ratio and cooling type</td></tr>
</table>

In order to usnderstand the substitution ratio (5%, 10%, 15%, 20%, 25%) according to Hwangtoh fineness, characteristics of mortar resulted from cooling method, series Ⅳ was experimented by using the activated Hwangtoh which was rapidly solidified in a furnace after being activated for one (1) hour at 800℃. Series Ⅴ was intended to understand the characteristics of Hwangtoh mortar according to the kinds of fine aggregate and average particle size while setting the average particle size as the three(3) levels of 4.76 mm, 2.36 mm, 1.18mm by using strong sand instead of standard sand. With regard to series Ⅵ, we set each Hwangtoh fineness at the level of 3 and mixed it in water-cement ratio at the level of 50%, 60%, 70% respectively. We also fixed the substitution ratio of activated Hwangtoh(800℃, rapid solidification) and the average particle size of strong sand as 1.18mm.

2.2 *Material and test method*

2.2.1 *Hwangtoh*

The Hwangtoh used in the experiment was produced in Gochang, Jeonnam province in Korea. The experiment was intended to understand the characteristics of mortar for each average particle size by using total three(3) levels of 43㎛, 13㎛, 8㎛ in order to investigate the appropriately required average particle size of it when we applied mortar as the substituting material for cement. Table 2 indicates the chemical compositions of Hwangtoh.

Table 2. Chemical Compositions of Hwangtoh

Chemical component	Ratio (%)	Chemical component	Ratio (%)
SiO2	42.5	CaO	0.57
Al2O3	36.6	K2O	0.41
Fe2O3	4.05	TiO2	0.23
MgO	0.69	Na2O	0.18

2.2.2 *Cement*

The cement used in this experiment is the ordinary Portland cement produced by D company in Korea which satisfies the standard of KS L 5201, and its chemical composition and physical property is as shown in Table 3, 4.

Table 3. Chemical Composition of Cement

Chemical component					
CaO	SiO2	Al2O3	MgO	Fe2O3	SO3
61.7	20.08	4.8	3.9	3.38	2.51

Table 4. Physical Property of Cement

Specific gravity	Fineness (㎠/g)	Soundness (%)	Set		Compressive strength (kgf/㎠)		
			First set(min)	Last set(min)	3day	7day	28day
3.15	3,466	0.10	303	460	224	274	360

2.2.3 *Fine Aggregate*

In order to analyze the correlation of physical property influencing extent of fine aggregate when we mixed mortar, we used the strong sand from Hwangryong River in Gwangju Metropolitan City by classified into three (3) level of its average particle size through filtering. Later, it was used as the comparative group in order to test the standard sand to test quality of concrete and mortar in accordance with KS L 5100 Table 5 indicates the physical property of strong sand used in the experiment.

Table 5. Physical Property of Fine Aggregate

Type	F.M	Specific gravity (g/㎤)		Absorptance (%)	Average size(diameter) (3)
		Whole drying	Surface drying		
River sand	2.70	2.51	2.55	1.86	· 4.76mm · 2.36mm · 1.18mm

2.3 *Method of Experiment*

Based upon KS L 5105, we made the specimen of this experiment d by using cubical plywood object of dimension of 5×5×5㎝. Also, we made the length change specimen to understand the dry shrinkage change by using steel mold with dimension of 2.5×2.5×28.5㎝. We compacted and made the specimen right after mixing, and measured the workability through the mortar flow experiment. With regard to the curing of specimen, two (2) levels were set in order to perform the comparative experiment on the mortar characteristics by curing condition according to the activation temperature of Hwangtoh: We performed the ordinary atmospheric curing and the underwater curing in an aquarium of the same temperature of 20℃. By using the universal testing machine, we measured the characteristics of compressive strength by aging: for example, in period of time such as 3 days, 7 days, 14 days, and 28 days. Also, in order to analyze the internal connective characteristics of the mortar matrix, we observed the micro connective characteristics of mortar through SEM analysis.

3 ANALYSIS ON PHYSICAL PROPERTY OF MORTAR SUPPLEMENTED WITH ACTIVATED HWANGTOH

In order to analyze the optimal condition of Hwangtoh's activation, we analyzed the correlation by each condition of activation and by physical property of mortar while composing the activation temperature, activation time, cooling method, fineness of Hwangtoh, substitution ratio, which are the main influencing factors in activation of Hwangtoh as variables of mixing experiment.

3.1 *Flow Characteristics with Activation Temperature*

The mortar characteristics are the factor to have an influence on workability and constructability: We intended to decide the workability and constructability or mortar while calculating the average value based upon KS F 2476. Figure 1 indicates the flow characteristics and its influence coefficient(SI) according to the activation time of Hwangtoh of which particle size is 13㎛ in the water-cement ratio of 60%.

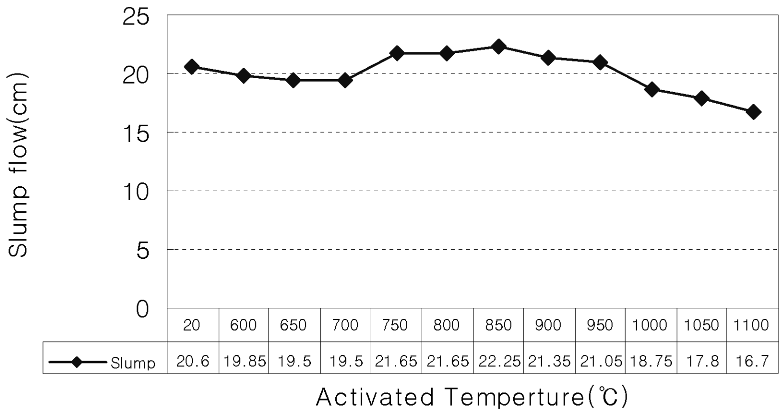
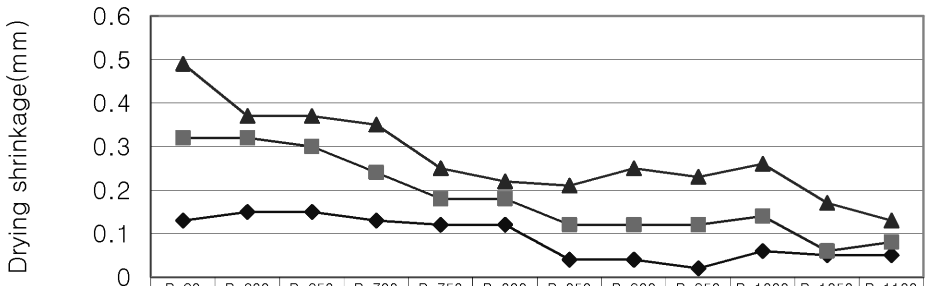


Figure 1 Flow Characteristics by Activation Temperature

Even though the flow value by activation temperature indicated the similar levels at range of 19~ 22cm by 950℃ in the state of room temperature within the error range of 20cm±2, it was remarkably reduced as below 17cm at the temperature of over 1,050℃. Hwangtoh indicated the solid state reaction in the temperature of over 1,050℃. Accordingly, we estimated that as we mixed it, the liquidity of mortar was decreased, and the flow value was reduced. In addition, according to the result to analyze the flow influence coefficient (SI=Sx/Ss) for the flow value (Sx) by each activation temperature based upon the flow measured value Ss (19cm) of standard mortar (W/C=60%) which was not supplemented with Hwangtoh, we found that the change was within the range of ±10% based on the temperature of 1,000℃.

3.2 *Characteristics of Dry Shrinkage Change with Activation Temperature*

Figure 2 indicates the dry shrinkage change values of mortar for activation temperature as the accumulated values after we measured them at 3 days, 7 days, 14 days, 28 days respectively.



	B-20	B-600	B-650	B-700	B-750	B-800	B-850	B-900	B-950	B-1000	B-1050	B-1100
28day	0.17	0.05	0.07	0.11	0.07	0.04	0.09	0.13	0.11	0.12	0.11	0.05
14day	0.19	0.17	0.15	0.11	0.06	0.06	0.08	0.08	0.1	0.08	0.01	0.03
7day	0.13	0.15	0.15	0.13	0.12	0.12	0.04	0.04	0.02	0.06	0.05	0.05

Figure 2 Characteristics of Dry Shrinkage Change by Activation Temperature

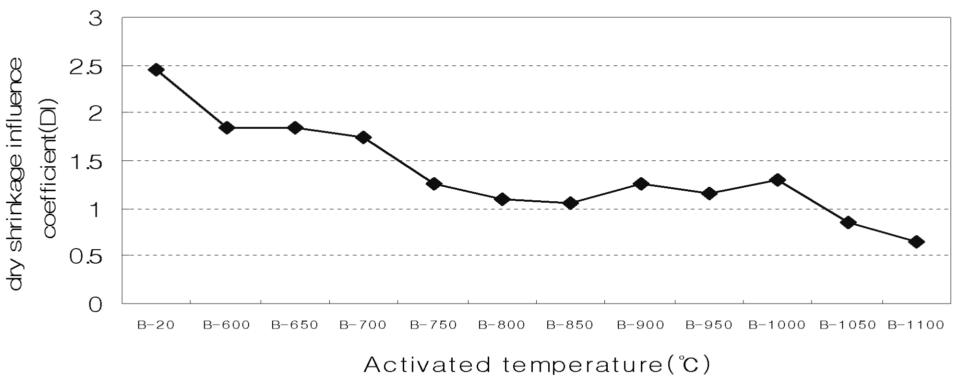


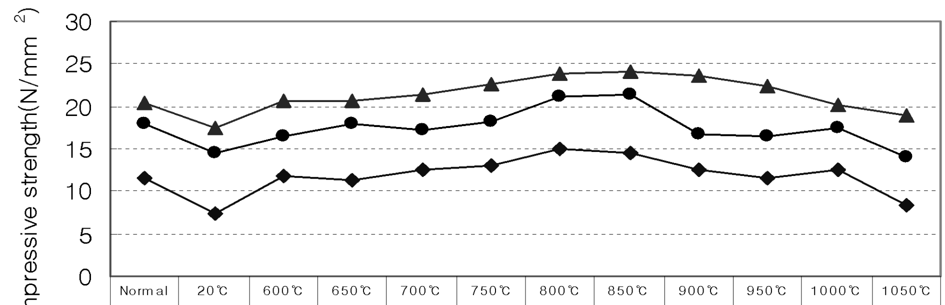
Figure 3 Dry Shrinkage Influence Coefficient (DI)

We found that the characteristics of dry shrinkage change according to its activation temperature was at the highest (0.49mm, DI=2.45) in ordinary raw Hwangtoh of room temperature state, and it was at the lowest (0.21mm, DI=1.05) at the temperature of 850℃. Also, the dry shrinkage ratio was indicated to increase again at the temperature of over 900℃ after it gradually decreased as the activation temperature increased (600~850℃); It is becauset the pozzolanic reaction shall decrease again at the temperature of over 900℃ after it gradually increases to the level of highest at the temperature of 800~850℃ as the activation temperature increases.

In Figure 3, the dry shrinkage influence coefficient(DI) is the numerical value of influencing extent according to the activation temperature which is the factor for experimental variables based upon Ds(Dry shrinkage value) 0.2mm of standard mortar. As the activation temperature increased at the room temperature, the influence coefficient gradually deceased to the similar value of Dx/Ds=1.05 with dry shrinkage value of standard mortar at the temperature of 850℃. It increased by 30% at the temperature range of 900~1,000℃, and decreased again by 35% or so at the temperature of over 1,000℃.

3.3 *Characteristics of Compressive Strength with Activation Temperature*

Figure 4, 5 indicate the characteristics of compressive strength and its influence coefficient(FI) of mortar supplemented with Hwangtoh which was substituted by 15% for each activation temperature. Based upon the 28-day compressive strength of 20.4(N/ mm2), Fs=1.0 of mortar not supplemented with Hwangtoh, the mortar supplemented with Hwangtoh at room temperature state was reduced by 14% or so with 17.55(N/mm2), FI(Fx/Fs)=0.86. But it showed the similar level at the temperature of 600~700℃. It was indicated as the highest level with 24(N/mm2), FI=1.18 at the temperature of 800~850℃ while increasing by 18%. It was, however, reduced as 19(N /mm2), FI=0.93 at the temperature of over 1050℃. In other words, we estimated that the pozzolanic reaction was at its highest level at the activation temperature of 800~ 850℃ and it decreased according to the solid state reaction of Hwangtoh at the temperature of over 1050℃.



	Normal	20℃	600℃	650℃	700℃	750℃	800℃	850℃	900℃	950℃	1000℃	1050℃
3day	11.45	7.45	11.9	11.35	12.5	12.95	15.1	14.45	12.5	11.5	12.5	8.45
7day	17.95	14.5	16.55	17.95	17.25	18.2	21.05	21.3	16.65	16.5	17.45	14
2day	20.4	17.55	20.55	20.7	21.3	22.55	23.95	24	23.7	22.45	20.2	19

Activatd temperature(℃)

Figure 4 Characteristics of Compressive Strength by Activation Temperature

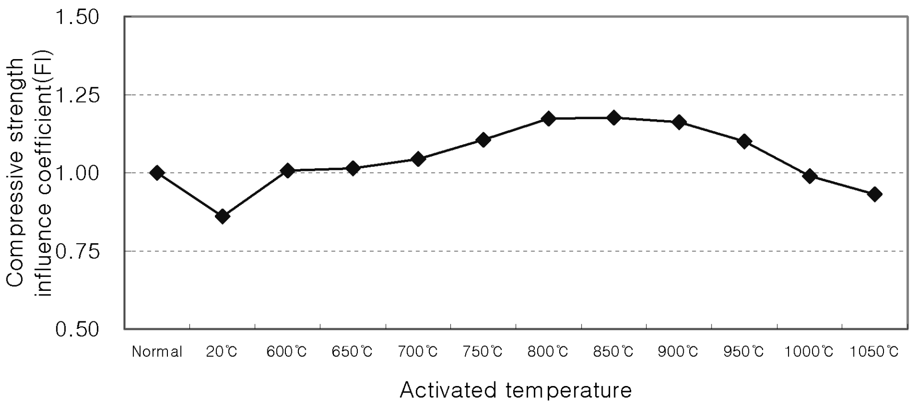
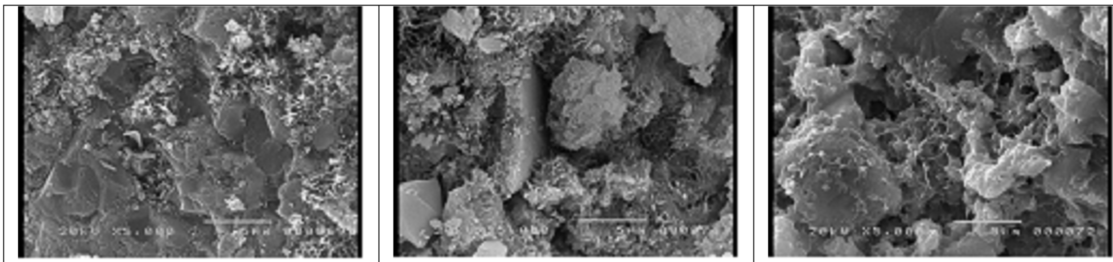


Figure 5 Compressive Strength Influence Coefficient by Activation Temperature

3.4 *SEM Analysis with Activation Temperature*

SEM analysis was intended to check the micro connective characteristics of each factor regarding variables of mortar supplemented with Hwangtoh. We connected $Ca(OH)_2$ which is the cement hydride with SiO_2 which is the activated Hwangtoh to have pozzolanic reaction. We examined on the hydride connective characteristics of C-S-H which was generated by this pozzolanic reaction.



20℃	800℃	1100℃

Figure 6 SEM Connective Characteristics by Activation Temperature

Figure 6 indicates the pictures magnified 5,000 times which we took while observing mortar at different activation temperatures: We could find that the Hwangtoh, which was activated at 800℃, had more apparent C-S-H structure than Hwangtoh mortar at ordinary room temperature. In the Hwangtoh mortar activated at 1,100℃, we found a lot of pores, and its C-S-H structure was not minute. In other words, we judged that the Hwangtoh mortar activated at 800℃ shall be most stable in cement hydride connective characteristics through SEM analysis.

4 CONCLUSION

In order to enhance the possibility to use Hwangtoh as the substituting material for cement to improve the environmental problem and eco-friendliness, we performed the basic study on physical properties of activated Hwangtoh mortar according to the diverse activating conditions and mixing/curing conditions of Hwangtoh which is the natural pozzolanic material.

The summaries of the results from the study are as follows:

(1) As a result of thermal response analysis of Hwangtoh, the weight of Hwangtoh increased again at around 600℃after endergaonic reaction appeared at the range of 450~470℃ at first. From this, we can estimate that the first starting temperature of Hwangtoh activation was less than 500℃, and the accelerating temperature for the activation was at the range of 600℃. But, Hwangtoh indicated the solid state reaction at temperature of over 1,050℃ while flow values were remarkably reduced and a number of internal pores caused the reduction of compressive strength. We concluded that it shall not be the appropriate temperature for the activation of Hwangtoh to be applicable as the building material.

(2) According to the result of analysis on micro hydride structure of mortar through SEM analysis, the Hwangtoh mortar, which was activated at 800℃, showed the minute structure of C-S-H while its pozzolanic reaction was indicated as high, and its dry shrinkage ratio was the smallest value with DI=1.05. Also, the compressive strength was indicated as the highest level at the activation temperature of 800~850℃. It increased by 18% with FI=1.18 compared to standard mortar. Therefore, we concluded that 800~850℃ shall be appropriate for the range of optimal activation temperature of Hwangtoh to be used for mortar.

(3) As for physical properties of mortar according to the activation time of Hwangtoh by 3 levels of Hwangtoh fineness, it showed the minutest structure of C-S-H while indicating FI=1.26 with Hwangtoh fineness of 13μm, and FI=1.51 for the activation time of one(1) hour. In this condition, the compressive strength was indicated as the highest level. Therefore, we

concluded that Hwangtoh fineness of 13㎛ and activation time of one(1) hour shall be the most appropriate condition in the aspect of mortar efficiency.

(4) As the result to analyze the physical properties of mortar according to cooling method and substitution ratio by each fineness of Hwangtoh, the compressive strength of Hwangtoh, which was rapidly solidified, was indicated as high as about 10% even though flow according to cooling methods showed the similar levels. Consequently, we concluded that the rapidly solidified Hwangtoh shall be in good activation state. In addition, the cement hydride structure became minute. Its compressive strength influence coefficient was indicated as high at 20% of Hwangtoh substitution ratio. Therefore, we concluded that the appropriate range of Hwangtoh substitution ratio shall be at 20%.

(5) According to the result of analysis on correlation coefficient for each factor of experimental variables which could influence on the compressive strength, with regard to the activation temperature, r=0.92 was indicated at temperature of less than 800℃ and r=-0.97 was at over 800℃. In activation time, it was r=0.89. r=0.69 was indicated in substitution ratio of Hwangtoh. As the correlation of compressive strength was indicated as high in this condition, we concluded that the reliability for these conditions shall be highly evaluated as mixing mortar.

(6) As for the condition for activation of Hwangtoh to be used as the admixture of mortar, we estimated that the appropriate condition by each factor of variables shall be the activation temperature at the range of 800~850℃, activation time of one(1) hour, cooling method of rapid solidification. Also, with regard to mixing/curing conditions of mortar, we concluded that the appropriate condition shall be the followings: Hwangtoh fineness of 13㎛, substitution ratio of 20%, fine aggregate of strong sand, average particle size of 2.36mm for fine aggregate, water-cement ratio of 60%(considering workability) and curing method of underwater curing.

ACKNOWLEDGEMENT

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REFERENCES

1. ACI 209, 1978, "Prediction of creep, shrinkage and temperature effects in concrete structure", American Concrete institute, Detroit
2. A.M.Neville, "Properties of Concrete", LONGMAN, Fourth and final edition
3. Braja M, Das, 1999 "Soil mechanics", pp.9~16
4. Dunster A. M., 2000 "The pozzolanic reaction of metakaolin and its effects on Portland cement hydration", Journal of Materials Science, 5-28
5. Haifa, July, I. Soroka, 1990 "Portland cement paste and concrete"
6. M. Frias, 2002 "The effect that the pozzolanic reaction of metakaolin has on the heat evolution in metakaolin cement mortars", Cement and Concrete research
7. P. Kumar Metha & Paulo J. M. Monteiro, "Concrete-Microstructure, Properties, and Materials"
8. R. F. Feldman & P. J. Sereda, 1990 Engineering Journal (Canada), Vol.53, No.8/9, pp.53~59
9. T. C. Powers & J. Am. Ceram. Soc., 1962, Vol 61, No.1, pp.1~5, 1958; and S. Brunauer, American Scientist, Vol.50, No1, pp.210-219

A study on the physical properties of hard concrete mixing various type of recycled aggregate

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ABSTRACT: Concrete waste causes serious problems in social and economic parts. Namely, construction industry will confront serious problems due to shortage of natural aggregate unless we don't improve and consider this problem. So, it is needed urgently to recycle these huge concrete wastes, and to develop substitution material as another type of recycling construction material in point of sustainable development. Current recycled aggregates are used in part of non-structure in building due to low strength, so, it is too effective to recycle it as structural material by increasing its low strength, because it could solve the shortage problem of aggregates for concrete and also increase the stability on demand and supply in economics. Thus, this study aims to select recycled aggregate for construction material to analyze the physical properties of recycled aggregate and concrete mixed it. Also, this study is going to analyze physical properties on concrete when mixing recycled aggregate into it on the point of view in sustainable part. This study contains experimental analysis and results of hard concrete mixing various types of recycled aggregate.

1 INTRODUCTION

Recycled aggregate is highly recommended to be research in a recent atmosphere in which the environmental protection rises as a matter of national concern: as the recycled aggregate can minimize the waste, and reduce the costs of waste treatment and energy use through the recycling of the happened waste. In addition, even the effect of natural resource protection and pollution prevention can be expected.

Therefore, in this study, a research on the properties of recycled aggregate concrete is to be conducted to examine the possibility of recycled aggregate's application, which was made from the concrete waste through fracturing and grinding, to the concrete, in order to correspond to the social requirement. Namely, this study aims at examining the physical property of the hard concrete for which recycled aggregate was used, by analyzing the property of hard concrete such as compressive strength, bending strength, modulus of elasticity, drying shrinkage, and freezing and thawing resistibility while making the concrete with the mixture of type 1, type 2, type 3 of recycled coarse aggregate and recycled fine aggregate based upon the property of recycled aggregate.

2 EXPERIMENTAL PLAN AND METHOD

2.1 *Experiment plan*

Table 1 indicates the experimental plan of this study for the experimental validation about physical property, drying shrinkage & durability of the concrete used recycled aggregate. 21.0MPa and 24.0MPa which are the compressive strength ranges most generally used in the current construction sites were set as the design strength of this study, and 300kg/㎥and 340kg/ were used for the cement unit content according to each design strength. In order to grasp the general properties of concrete according to the substitution ratio of recycled aggregate, the mix plan for concrete was set while substituting the substitution ratio of coarse aggregate and fine aggregate with 0, 30, 60, 100% based upon the volume of aggregate.

Table 1Test plan of recycled aggregate concrete

	Division	Type of recycled agg.		Substitution ratio of recycled agg.(%)		W/C(%)	Design strength (MPa)	Fly ash (%)	AE agent (%)
		Coarse agg.	Fine agg.	Coarse agg.	Fine agg.				
Mixing Proportion	Factor	Type 1 Type 2 Type 3	Natural sand Recycled sand	0 30 60 100	0 30 60 100	50	21.0 24.0*	10	0.5
	Sign	Ⅰ Ⅱ Ⅲ	-	c-0 c-30 c-60 c-100	f-0 f-30 f-60 f-100	-	A B	-	-
Test items	Hard concrete	. Compressive strength (3, 7, 28, 56 days) . Bending strength (28, 56 days) . Modulus of elasticity (28 days) . Drying shrinkage (3, 7, 14, 28 days) . Freezing and thawing resistibility (0, 50, 100, 150, 200, 250, 300cycle)							

Notice ;
- * : It applies to factor only when mixing type 1 of recycled coarse agg.
- A : Design strength(MPa)
- Ⅰ, Ⅱ, Ⅲ : a type of recycled coarse aggregate
- c : Substitution ratio of recycled coarse aggregate
- f : Substitution ratio of recycled fine aggregate

This study also aims at examining the general physical property of recycled aggregate by setting the slump range at 12.0±2.5cm, and W/C ratio(water-cement ratio) at 50% while arranging each unit water content at the two levels of 150kg/㎥ and 170kg/㎥ respectively. In order to prevent the alkali aggregate reaction of recycled aggregate in advance, the use of admixture has been reported as essential and quite effective. Consequently, considering that its appropriate substitution ratio reportedly is 7~12%, the fly ash most commonly used among admixtures was used while substituted as 10% based upon the weight of concrete.

2.2 *Material and test method*

2.2.1 *Cement*

The cement used in the experiment is the ordinary Portland cement which is the product of S cement company that conforms to the regulations of KS(Korea Standard: referred as KS hereon) L 5201. Its physical property and chemical components are indicated in Table 2, 3.

2.2.2 *Aggregate*

Concerning the recycled aggregate used in the research, the coarse aggregate was divided into three(3) types, and the fine aggregate was divided into two(2) types according to the percentage of water absorption as applying KS F 2573(Recycled Aggregate for Concrete) which separates its purpose of use according to the quality.

① Coarse Aggregate

Among the coarse aggregate, the crushed aggregate was used as the ordinary coarse aggregate, and the recycled coarse aggregate was used while divided into three (3) types. With regard to the condition of aggregate in store, the mixing was performed by using the aggregate stored indoor for over 12 hours after water was sprayed on it in order to meet the condition of Pre-Wetting. The physical property of coarse aggregate is indicated in Table 4.

Table 2. Physical properties of cement

Gravity	Fineness (㎠/g)	Set		Soundness (%)	Compressive strength(MPa)		
		First set(min)	Last set(min)		3 days	7 days	29days
3.15	3,400	230	390	0.1	23.0	30.0	41.0

Table 3. Chemical proportion of cement

Ingredient	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	SO_3	Ignition loss	Free CaO	Insol.
Proportion (%)	61.3	21.1	5.2	4.0	2.8	2.4	2.0	0.6	0.2

Table 4. Physical properties of coarse aggregate

Type		Gravity (g/㎤)	water absorption (%)	Abrasion ratio (%)	Quantity of material per unit volume of concrete (kg/L)	Absolute volume(%)
Ordinary agg.	Crushed agg.	2.60	1.23	23.50	1,509	60.80
Recycled agg.	Type 1	2.58	1.85	16.14	1,560	60.47
	Type 2	2.35	5.25	30.30	1,380	59.13
	Type 3	2.28	8.03	43.90	1.220	58.10

② Fine Aggregate

The physical property of fine aggregate is shown in Table 5. The washed sea sand was used as the ordinary fine aggregate, and the product of A company of which property was most outstanding amongst the samples for the analysis was used as the recycled fine aggregate. It was also used after being stored indoor for more than 12 hours while the enough water was sprayed on it.

Table 5. Physical properties of fine aggregate

Type		Gravity (g/㎤)	Water absorption (%)	Fineness modulus	Quantity of material per unit volume of concrete (kg/L)	Absolute volume (%)
Ordinary agg.	natural sand	2.59	0.90	2.62	1.816	63.6
Recycled fine agg.	A	2.33	5.10	2.50	1.430	61.5

3 PHYSICAL PROPERTIES OF HARD CONCRETE MIXING RECYCLED AGGREGATE

Table 6 is the result of experiment on the recycled aggregate concrete used the mixture of crushed aggregate(referred as NA-natural aggregate hereon), sea sand(referred as NS-natural sand hereon), recycled coarse aggregate(referred as RA-recycled aggregate hereon), and recycled fine aggregate(referred as RS-recycled sand hereon).

As follows are the compressive strength of recycled aggregate concrete according to the property of recycled aggregate and the characteristics of its accompanying modulus of elasticity, drying shrinkage, and freezing and thawing resistibility.

Table 6. The result of experiment on the recycled aggregate concrete

Design strength	Division	Hard concrete				
		compressive strength (MPa)	bending strength (MPa)	Modulus of elasticity (×105㎏/㎠)	Drying shrinkage (×10-4)	freezing and thawing resistibility (%)
21.0 MPa	A/ Ⅰ /c-0/f-0	35.4	2.9	3.48	1.857	89.1
	A/ Ⅰ /c-0/f-100	29.8	2.5	3.08	2.239	84.8
	A/ Ⅰ /c-30/f-0	33.8	2.8	3.39	1.535	87.5
	A/ Ⅰ /c-30/f-30	31.4	2.5	3.69	1.728	84.3
	A/ Ⅰ /c-30/f-60	32.2	2.6	3.53	2.207	82.7
	A/ Ⅰ /c-30/f-100	30.7	2.4	3.06	2.476	84.8
	A/ Ⅰ /c-60/f-0	34.6	2.9	3.13	2.396	86.5
	A/ Ⅰ /c-60/f-100	31.2	2.5	3.01	2.634	83.5
	A/ Ⅰ /c-100/f-0	31.5	2.6	3.07	2.815	84.0
	A/ Ⅰ /c-100/f-100	29.4	2.4	2.95	3.016	82.5
	A/ Ⅱ /c-0/f-0	35.4	2.9	3.48	1.857	89.1
	A/ Ⅱ /c-0/f-100	29.8	2.5	3.08	2.239	84.8
	A/ Ⅱ /c-30/f-0	33.6	2.8	3.25	2.015	82.5
	A/ Ⅱ /c-30/f-30	32.5	2.7	3.07	2.441	81.4
	A/ Ⅱ /c-30/f-60	31.4	2.6	3.04	2.685	79.4
	A/ Ⅱ /c-30/f-100	30.9	2.4	2.65	2.992	78.5
	A/ Ⅱ /c-60/f-0	34.4	2.9	2.79	3.271	79.5
	A/ Ⅱ /c-60/f-100	29.8	2.5	2.56	3.394	76.7
	A/ Ⅱ /c-100/f-0	32.8	3.1	2.68	3.654	77.6
	A/ Ⅱ /c-100/f-100	29.8	2.3	2.43	3.898	75.3
	A/Ⅲ/c-0/f-0	35.4	2.9	3.48	1.857	89.1
	A/Ⅲ/c-0/f-100	29.8	2.3	3.08	2.239	84.8
	A/Ⅲ/c-30/f-0	26.2	2.4	2.53	3.194	72.8
	A/Ⅲ/c-30/f-30	24.8	2.2	2.33	3.251	69.1
	A/Ⅲ/c-30/f-60	23.8	2.2	2.69	4.033	67.7
	A/Ⅲ/c-30/f-100	21.2	2.0	2.42	4.261	66.4
	A/Ⅲ/c-60/f-0	24.9	1.9	2.05	4.396	68.9
	A/Ⅲ/c-60/f-100	21.2	1.6	2.19	4.938	65.3
	A/Ⅲ/c-100/f-0	25.0	2.2	2.34	4.832	66.2
	A/Ⅲ/c-100/f-100	20.3	1.8	2.08	5.483	61.5
24.0 MPa	B/ Ⅰ /c-0/f-0	33.1	2.9	3.69	1.483	90.5
	B/ Ⅰ /c-0/f-100	31.3	2.7	3.48	1.975	87.4
	B/ Ⅰ /c-30/f-0	36.9	3.2	3.38	1.542	86.2
	B/ Ⅰ /c-30/f-30	36.7	3.1	3.64	1.632	83.6
	B/ Ⅰ /c-30/f-60	35.1	3.2	3.27	1.902	84.5
	B/ Ⅰ /c-30/f-100	34.2	3.0	3.16	2.108	85.4
	B/ Ⅰ /c-60/f-0	33.8	2.9	3.32	2.235	84.4
	B/ Ⅰ /c-60/f-100	32.9	2.7	3.28	2.545	83.4
	B/ Ⅰ /c-100/f-0	35.1	3.0	3.13	2.754	83.6
	B/ Ⅰ /c-100/f-100	30.5	2.5	3.08	2.961	82.4

3.1 *Absorption ratio and compressive strength*

Figure 1 indicates the compressive strength of recycled aggregate concrete corresponding to the absorption of recycled aggregate. On the day of 28th, the compressive strength of ordinary concrete used NA+NS was indicated as 35.4MPa, and the compressive strength of concrete used NA+RS was indicated as 29.8MPa. There was a trend that the compressive strength of recycled aggregate concrete would decrease by about 16% compared to the ordinary concrete according to using RS. Amongst the concrete used type 1 of RA, the compressive strength of type 1 of RA+NS was 31.5 ~ 34.6MPa while showing the strength development of about 96% of the ordinary concrete used NA+NS, and the compressive strength of type 1 of RA+RS was indicated 29.4 ~ 31.2MPa while showing the characteristics that its strength development increased by 3% or so rather than NA+RS. With regard to the compressive strength of concrete used type 2 of RA, type 2 of RA+NS was at the range of 30.5 ~ 32.0MPa indicating the characteristics of strength development almost similar with type 1 of RA, and type 2 of RA+RS was indicated as 27.7 ~ 28.7MPa while showing that its the compressive strength decreased by about 7~11% compared to type 1 of RA+RS.

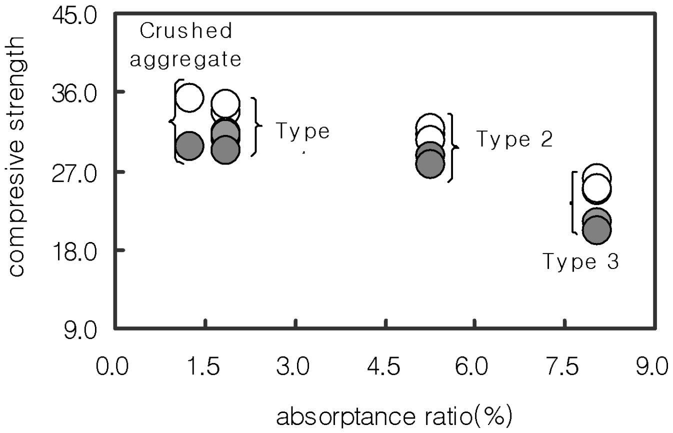

Figure 1 Compressive strength with absorptance ratio

Type 1 of which RA's density was over 2.50g/㎤, and its absorption ratio was 1.85% indicated the property almost similar with NA. RA Type 2 with the density of 2.35g/㎤ and absorption ratio of 5.25%, of which quality was a little worse than RA Type 1, indicated the similar compressive strength with NA and RA Type 1. The compressive strength of concrete used type 3 of RA was, however, indicated as much decreased compared to ordinary concrete unlike type 1 and type 2 of RA. The compressive strength of RA Type 3+NS was at the range of 25.0 ~ 26.2MPa showing the characteristics that its compressive strength decreased by 26% or so compared to ordinary concrete used NA+NS. RA Type 3+RS used RS was indicated as 20.3 ~ 21.2MPa while its compressive strength decreased by about 40% than NA+NS, and by about 29% than NA+RS, which is thought to be caused by the characteristics accompanying the degradation of aggregate quality.

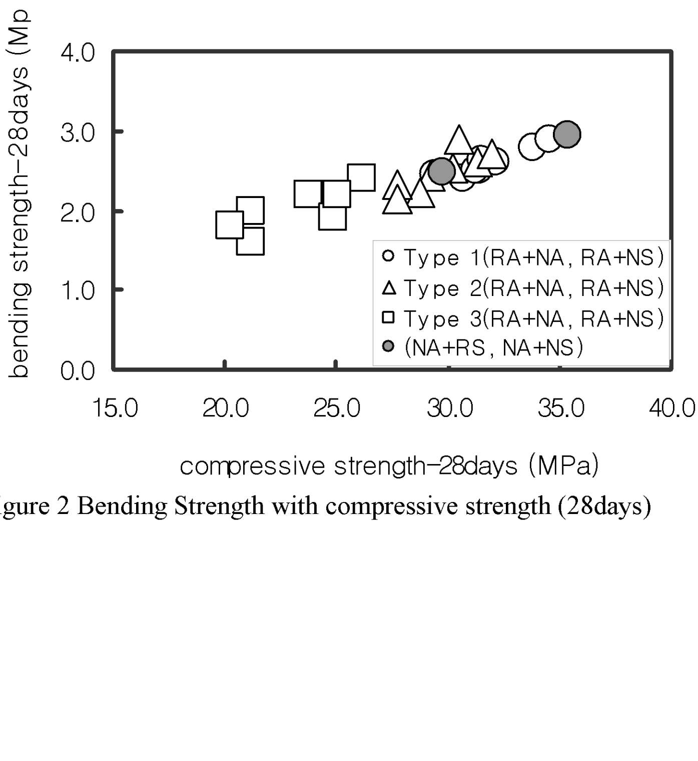

Figure 2 Bending Strength with compressive strength (28days)

As shown in Figure 2, not only the compressive strength but also bending strength characteristics of recycled aggregate concrete was indicated to be apparently different according to the quality of recycled aggregate. The concrete used RA Type 3 indicated 1.60 ~ 2.40MPa while the ordinary concrete and one used RA Type 1 and RA Type 2 showed 2.10 ~ 2.90MPa. As examining the characteristics of compressive strength and bending strength of recycled aggregate concrete, the concrete used RA Type 1 and RA Type indicated 90% or so of characteristics compared to the ordinary concrete, and consequently, it is expected to be very good in application to the concrete. As the concrete used RA Type 3 showed the characteristics of about 30% of reduction, it is recommendable to pay much attention to its application to the concrete for structures.

3.2 *Compressive strength and modulus of elasticity*

Figure 3 indicates the relation in between compressive strength and modulus of elasticity in recycled aggregate concrete. According to this, the larger the compressive strength of recycled aggregate concrete became, the higher the modulus of elasticity got as well. It was confirmed that the modulus of elasticity of concrete used RA Type 1 indicated the similar value with the one of concrete used NA and NS.

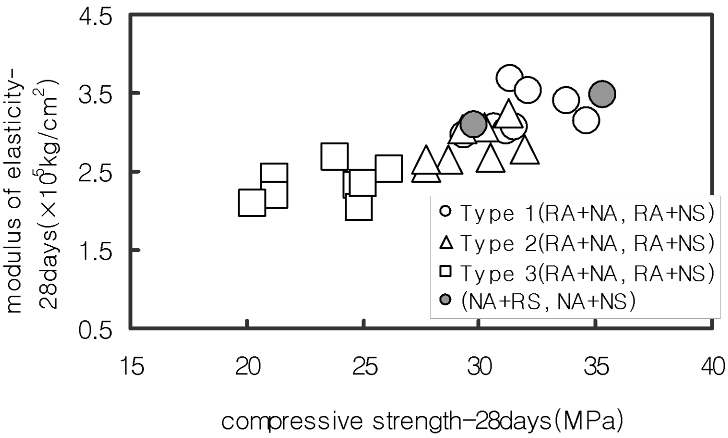

Figure 3 Modulus of elasticity with compressive

The moduls of elasticity of the ordinary concrete used NA and NS was 3.48×10^5kg/cm^2 and NA+RS used the recycled aggregate indicated 3.08×10^5kg/cm^2 as its modulus of elasticity. As for the concrete used RA Type 1, RA Type 1+NS and RA Type 1+RS showed 2.95 ~ 3.69×105 kg/㎠ which was similar with the value of NA+RS. But, concerning the concrete used RA Type 2, RA Type 2+NS and RA Type 2+RS indicated 2.56 ~ 3.25×10^5kg/㎠ which was decreased by 18.5% or so compared to the ordinary concrete, and decreased by 12.2% at an average compared to RA Type 1+NS and RA1 Type 1+RS. RA Type 3+NS and RA Type 3+RS showed 2.05 ~ 2.69×10^5kg/㎠ which was decreased by 33.1% at an average compared to the ordinary concrete, and decreased by 27.9% or so compared to RA Type 1+NS and RA Type 1+RS: Its range of reduction was quite large.

Owing to this characteristic, it is expected that as the concrete used RA Type 3 indicates much lower modulus of elasticity compared to the ordinary concrete, it shall be very difficult to be used as the concrete aggregate for structures of building.

3.3 *Compressive strength and drying shrinkage*

Figure 4 indicates the result of an experiment on the length change ratio according to drying shrinkage of recycled aggregate concrete. There was a trend that the lower the quality of recycled aggregate became, the lower it became as well compared to the ordinary concrete.

First, RA Type 1+NS and RA1 Type 1+RS which is the concrete used RA Type 1 indicated -1.5 ~ -3.0×10^{-4}, and -2.4×10^{-4} on the average which was larger by about 27% than the concrete used NA+NS which was indicated as -1.8×10^{-4}. But, its length change ratio was small to the extent that in some cases, it was better than the ordinary concrete used NA+NS.

RA Type 2+NS and RA Type 2+RS which is the concrete used RA Type 2 indicated -2.0 ~ -3.9×10^{4}, and -3.0×10^{-4} on the average which was larger by about 64% on the average than the ordinary concrete. There were, however, types which indicated the characteristics almost similar with the ordinary concrete according to the substitution ratio of RA. In general, its length change ratio was a little higher than the ordinary concrete. Therefore, it is anticipated that a good value can be surely secured according to the adjustment of substitution ratio.

However, RA Type 3+NS and RA Type 3+RS which is the concrete used RA Type 3 indicated -3.2 ~ -5.5×10^{-4}, and -4.3×10^{-4} on the average which was larger by about 132% on the average than the ordinary concrete. Accordingly, the preparation for this is required, and it is expected that RA Type 3 shall be difficult to be used as concrete aggregate for structures of buildings.

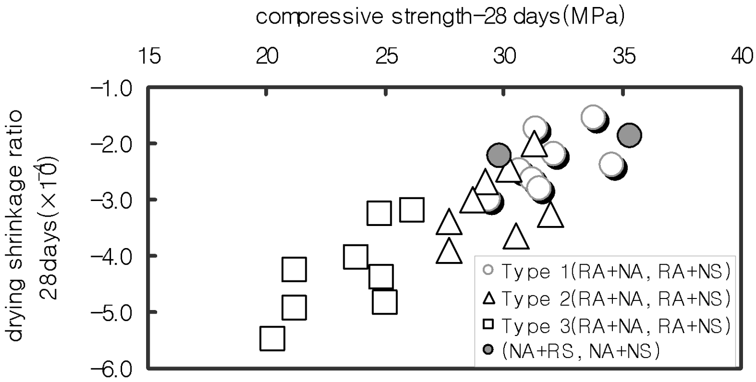

Figure 4 Drying shrinkage with compressive

4 CONCLUSION

A research on the physical property of the concrete used recycled aggregate was performed in this study in order to examine the eco-friendliness corresponding to recycling the construction waste, energy reduction, and the possibility of utilization of recycled aggregate in the aspect of environmental protection as a countermeasure to the increase of aggregate demand in the concrete industry. With regard to this point, conducted were the experiment and analysis on compressive strength, bending strength, modulus of elasticity, drying shrinkage, and freezing and thawing resistibility which is the property of hard concrete.

The summaries of the results from the study are as follows:

(1) As for the compressive strength and bending strength, at the design strength of 21.0MPa, they were indicated as in the range of 29.4 ~ 34.6MPa and 2.40 ~ 2.90MPa respectively in cased of the concrete used RA Type 1, and they were at the range of 27.7 ~ 32.2MPa and 2.10 ~ 2.90MPa respectively in case of the concrete used RA Type 2: which did not show much difference from the ordinary concrete. But, in case of the concrete used RA Type 3, they were at the range of 20.3 ~ 26.2MPa and 1.60 ~ 2.40MPa; which indicated that its strength development was worse than RA Type 1 and RA Type 2. Consequently, as considering the safety factor taking the construction environment at the construction site into account, it is desirable to pay much attention in order to use RA Type 3 as the concrete aggregate.

(2) While the modulus of elasticity of ordinary concrete is 3.48×10^{5}kg/㎠, at the design strength of 21.0MPa, the modulus of elasticity of the concrete used RA Type 1 was 2.95 ~ 3.69×10^{5}kg/㎠, and it was indicated as 2.56 ~ 3.25×10^{5}kg/㎠ in case of the concrete used RA Type 2. In case of the concrete used RA Type 3, it was 2.05 ~ 2.69×10^{5}kg/㎠. Like this, there was a trend that as the absorption ratio or recycled aggregate became higher and the substitution ratio of recycled aggregate increased, the modulus of elasticity of recycled aggregate concrete became lower.

(3) At the design strength of 21.0MPa, the drying shrinkage was indicated as -1.5 ~ -3.0×10^{-4} in case of the concrete used RA Type, and in case of the concrete used RA Type 2, it was -2.0

~ -3.9×10^{-4}. It was shown at the range of -3.2 ~ -5.5×10^{-4} in case of the concrete used RA Type 3:as the absorption ratio and substitution ratio increased, the drying shrinkage increased as well. Much attention is required to recycle RA Type 3 as the concrete aggregate as its drying shrinkage usually is 2.2~4.4 times larger than the one of ordinary concrete.

(4) At the design strength of 21.0MPa에, the carbonation was at the range of 5.4 ~ 6.2㎜ in case of the concrete used RA Type 1, and it was at the range of 6.3 ~ 7.1㎜ in case of the concrete used RA Type 2. In case of the concrete used RA Type 3, it was indicated as 9.5 ~ 12.6㎜: There was a trend that as the absorption ratio or recycled aggregate became higher and the substitution ratio of recycled aggregate increased, the carbonation increased.

ACKNOWLEDGEMENT

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REFERENCES

1) Hansen, T.C. 1992, Recycled of Demolished concrete and Masonry, RILEM Report 6, E&FN SPON
2) Ravindrajah, R.S.& Loo, Y.H. & Tam, T.C. 1987, Recycled concrete as fine and coarse aggregate in concrete, Magazine of Concrete Research. 39, No.141, pp.214 ~ 220
3) Hasaba, S.& Kawamura, M. & Toriik, K., et al. 1981, Drying shrinkage and durability of concrete made of recycled concrete aggregates. Translation of the Japan Concrete Institute, 3, pp.55 ~ 60 (Additional information obtained from background report in Japanese)
4) Malhotra, V.M. Use of recycled concrete as a new aggregate, Proceedings of Symposium on Energy and Resource Conservation in the Cement and Concrete Industry, CANMET, Report No. 76-8, Ottawa.
5) Rottler, G. 1985, Dauerhaftigkeit von Recyclingbetonen bei Frost-Tausalz-Beanspruchung, Diplomarbeit, Institut für Massivbau und Baustofftechnologie, Universität Karlsruhe, Postfach 6380, 7500 Karlsruhe 1. Bundesrepublik Deutschland.(In German)

Sustainable steel buildings through Natural Fire Safety Concept

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ABSTRACT:

Sustainable construction means optimized utilization of raw materials and energy during their entire life cycle and reducing to a minimum any adverse effects on the environment. This contribution describes the Global Natural Fire Safety Concept (NFSC) and highlights its importance for sustainable construction. In contrary to conventional methods of guaranteeing structural fire protection for steel structures with board claddings or reactive (intumescent) fire protection systems, active fire fighting measures as well as probabilistic aspects on the fire occurrence are respected. Hence by optimizing the material use, the costs for fire protection are strongly reduced. The application of the NFSC is described on the basis of realized buildings. The NFSC produces real safety for people and at the same time guarantees the needed fire resistance for the structure in real life. It was established in the scope of European Research sponsored by the ECSC and is now fully considered in the European Standards.

1 INTRODUCTION

The use of steel as construction material for buildings is a first step towards ecological, sustainable building. The entirety of the production of steel beams and columns are made from indefinitely recyclable ferrous scrap. Steel is a sustainable, flexible material by fulfilling all esthetic expectations [1]. But at elevated temperatures the mechanical properties of steel (and concrete) are decreasing.
The traditional way of “fire design” is the cladding of columns and beams with fireproof materials (spray, board or paint). Because of the cladding the temperature increase in the construction is reduced and the member resist to the fire for a longer time. No information about the real behavior of the structure and the safety is given by this method. In the last decades a new approach of fire design was developed. By taking the active fire fighting measures (e.g. sprinkler) and the real fire evolution into account, the NFSC is a more realistic approach for the structural safety in case of fire. The material use is optimized; the costs needed for fire protection are strongly reduced and, in some cases, omitted [2]. Compared to modern Fire Safety Concepts, the traditional method is a waste of material, resources and energy.

2 EVOLUTION OF REAL FIRES

A real fire can be distinguished in three different phases (Figure 1): First, the pre flashover or growth phase (A), the fire load begins to burn; temperature within the compartment varies from one point to another, with important gradients and there is a gradual propagation of the fire. The average temperature in the compartment grows; if it reaches about 300°C to 500°C, the upper layers are subjected to a sudden ignition called flashover and the fire develops fully.

In the second phase (B), after flashover, the gas temperature increases very rapidly from about 500°C to a peak value, often in excess of 1000°C, and becomes practically uniform throughout the compartment. After this phase, the available fire load begins to decrease and the gas temperature necessarily falls (C, cooling phase). The fire severity and duration of these phases depend on many parameters: The amount and distribution of combustible materials (fire load) ; the burning rate of these materials; the ventilation conditions (openings); the compartment geometry and the thermal properties of surrounding walls.

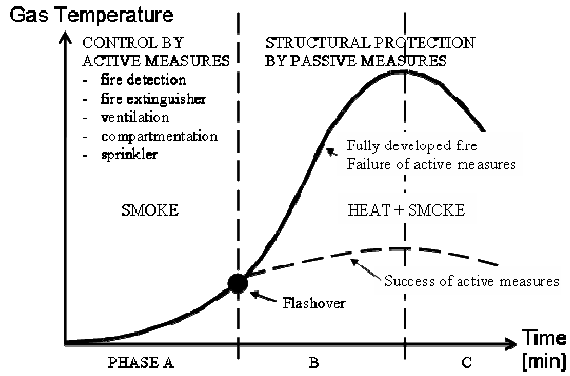

Figure 1 : Realistic Fire Evolution

There are two types of fire, controlled respectively by ventilation and by fuel (fire load) characteristics (Figure 2). Ventilation controlled fires take place when openings of the compartment are relatively small compared to its overall dimensions. An increase of the opening areas results in higher peak temperatures and a faster decay phase. If the air supply is sufficient, so that the fire is fuel controlled, the amount of fire load and its arrangement have a decisive influence on fire severity.

To summarize, short and relatively benign fires can be expected when the air flow rate into a compartment is rather high and the fire load density rather small. On the other hand, higher temperatures and longer durations take place with higher fire load densities and little heat dissipation through openings and walls. The design fire exposure, together with structural data for the proposed structure, thermal properties of the structural materials and coefficients of heat transfer for various surfaces of the structure, give the necessary information to determine the temperature development in the fire exposed structure. Together with the mechanical properties of structural materials, the load characteristics, and the variation of resistant forces and moments, it is possible to determine thermal stresses and load bearing capacity in fire conditions [3].

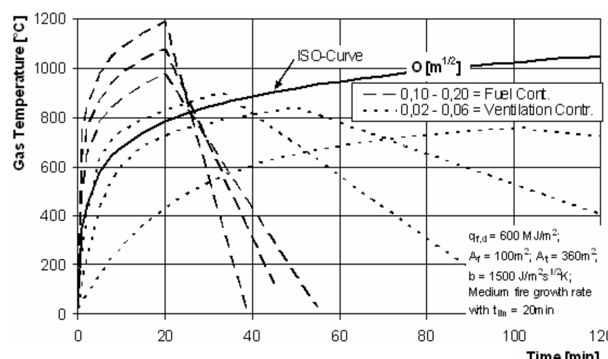

Figure 2: Temperature Time Curves acc. to EN 1991-1-2: 2002, Annex A + ISO

3 THE NATURAL FIRE SAFETY CONCEPT (NFSC)

The NFSC or Global Fire Safety Concept, is a more realistic and credible approach for the analysis of structural safety in case of fire. It takes account of active fire fighting measures and real fire characteristics. In June 1994 the European Research "Natural Fire Safety Concept" started. It has been undertaken by 11 European partners and is coordinated by PROFIL-ARBED- Research. The research project ended in June 1998 [2].

The NFSC takes into account: a) the building characteristics relevant to fire growth: fire scenario, fire load, pyrolysis rate, compartment type and ventilation conditions; b) quantifies the risk of fire start and considers the influence of active fire fighting measures and occupation time; this risk analysis is based on probabilities deduced from European databases of real fires;

c) deduces from the previous step, design values for the main parameters such as the fire load; d) determines the design heating curve as a function of the design fire load that takes into account the fire risk and therefore the fire fighting measures; e) simulates the global behavior of the structure submitted to the design heating curve and the static load in case of fire; f) deduces the fire resistance time nat $t_{fi,d}$; this may often be infinite such that the structure is able to support the loads from the beginning to the end of the fire; g) verifies the safety of the structure by comparing the fire resistance time nat $t_{fi,d}$ with the required time depending of the evacuation time and the consequences of the failure.

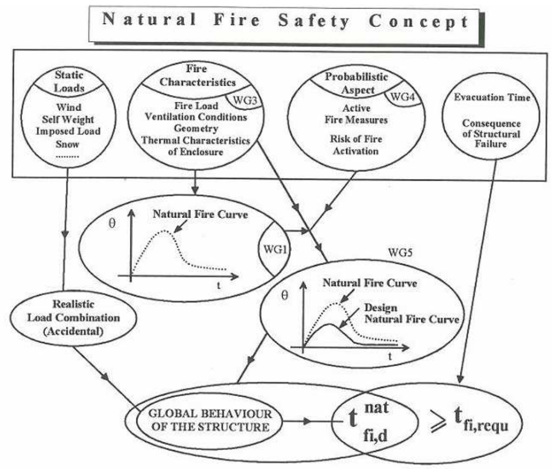

Figure 3 : Natural Fire Safety Concept

The European Research on the NFSC [2] allowed to analyze natural fire models based on more than 100 new natural fire tests; consequently permitting to consider natural fire models in the European Standard. Furthermore these natural fire models allow, through design fire load, to consider the beneficial effect of the active fire safety measures i.e. by safe escape ways, proper smoke venting or by conveniently designed and maintained sprinkler systems. Also the danger of fire activation is taken into account. Thus the so-called Global Fire Safety Concept produces real safety for people and at the same time permits to guarantee the required structural fire resistance in real live. A prescription of the verification of steel structures in case of fire according to the European Standards is given in the following chapter.

4 THE NFSC AND THE EUROPEAN STANDARDS

According to the EN [6, 7, 8] the design of structural members in fire situations has to be carried out at the ultimate limit state. It should be verified that, during the relevant duration of fire exposure t:

$$E_{fi,d,t} \leq R_{fi,d,t} \tag{1}$$

where $E_{fi,d,t}$ is the design effect of the actions in the fire situation determined from the accidental combination rule, including effects of thermal expansions and deformations and $R_{fi,d,t}$ is the design value of the corresponding resistance in the fire situation. As an alternative to (1) the verification may be carried out in the time or the temperature domain [7].

4.1 *Mechanical Actions*

The probability of the combined occurrence of a fire in a building and an extremely high level of mechanical loads is very small. Therefore actions on structures from fire exposure are classified as accidental actions and shall be combined by using the following accidental combination:

$$E_{fi,d,t} = \sum G_{k,j} + (\psi_{1,1} \text{ or } \psi_{2,1}) * Q_{k,1} + \sum \psi_{2,i} * Q_{k,i} + \sum A_{d,t} \tag{2}$$

where $G_{k,j}$ is the characteristic value of a permanent action j; $Q_{k,1}$ is the characteristic value of the leading variable action 1; $Q_{k,i}$ is the characteristic value of the accompanying variable action i; $\psi_{1,1}$, $\psi_{2,1}$, $\psi_{2,i}$ are combination factors for buildings according to Table A1.1 of [6] and A_d is the design value of an accidental action resulting from the fire exposure. The accidental action is represented by the temperature effect on the material properties and the indirect thermal actions created either by deformations and expansions caused by the temperature increase in the structural elements, where as a consequence internal forces and moments may be initiated, P-δ effect included either by thermal gradients in cross-sections leading to internal stresses. Generally this leads in the accidental fire situation to a loading which corresponds from 50% to 70% of the ultimate design value of actions at room temperature.

4.2 *Design resistance of structural steel in fire*

At elevated temperatures the mechanical properties of steel are decreasing [8]. In comparison to room temperature (20°C), the modulus of elasticity decreases at 100°C and the yield strength at 400°C (Figure 3).

Thus the design resistance of steel in fire situation depends on the thermal actions and the material properties at elevated temperatures. To determine the gas temperatures in the compartment the appropriate temperature-time curve has to be defined first. Then the increase of the temperature in the structural member can be calculated by using simple calculation methods or advanced calculation methods. The design resistance is determined with the temperature and the mechanical properties at elevated temperatures.

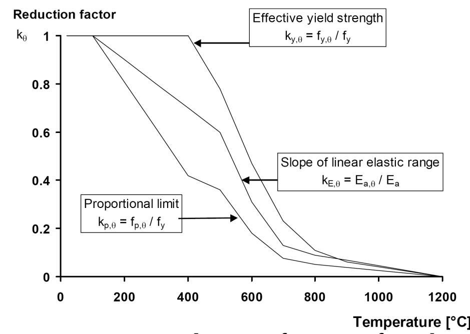

Figure 4: Reduction factors of carbon steel at elevated temperatures

4.3 *Thermal Actions*

The thermal actions are given by the net heat flux h_{net} [W/m^2] to the surface of the member. On fire exposed surfaces the net heat flux should be determined by considering heat transfer by convection and radiation [7].

$$\dot{h}_{net} = \dot{h}_{net,c} + \dot{h}_{net,r} \qquad [\mathrm{W/m^2}] \qquad (3)$$

The net convective heat flux component should be determined by:

$$\dot{h}_{net,c} = \alpha_c * \left(\theta_g - \theta_m\right) \qquad [\mathrm{W/m^2}] \qquad (4)$$

with α_c is the coefficient of heat transfer by convection [W/m^{2}K]; Θ_g is the gas temperature in the vicinity of the fire exposed member [°C] and Θ_m is the surface temperature of the member [°C]. To define the gas temperatures Θ_g, [7] gives the opportunity to use Nominal temperature-time curves (= ISO fire curve) and Natural fire models with parametric temperature-time curves.

4.3.1 *Nominal temperature-time curves*

In EN 1991-1-2: 2002 [7] three nominal temperature-time curves are given. The standard temperature-time curve (or ISO fire curve) is given by:

$$\Theta_g = 20 + 345 * \log_{10} * \left(8 * t + 1\right) \qquad [°\mathrm{C}] \qquad (5)$$

Where t is the time [min] and the coefficient of heat transfer by convection α_c = 25 W/m^{2}K. This fire curve does not represent realistic fire conditions in a compartment. The temperature is always increasing; the cooling phase and the real fire load of the compartment are not considered. This curve has no probabilistic background. The real fire evolution is not considered and it is not possible to calculate realistic temperatures with this curve. But this curve is simple to handle (only one parameter, the time t).

4.3.2 *Natural fire models – parametric temperature-time curves*

In the last decade modern design models to describe the real fire behaviour are developed. These natural fire models take into account the main parameters which influence the growth and development of fires. Natural fires depend substantially on fire loads, openings and thermal properties of surrounding structure. The gas temperature in the compartment can be determined with parametric temperature-time curves. These curves are considering the ventilation by an opening factor and the design value of the fire load density [7, Annex A].

Also advanced fire models taking into account the gas properties, the mass and the energy exchange are given in [7, Annex D]. A distinction is made between one-zone models, assuming a uniform, time dependent temperature distribution in the compartment and two-zone models assuming an upper layer with time dependent thickness and with time dependent uniform temperature, as well as lower layer with a time dependent uniform and lower temperature.
An essential parameter in advanced fire models is the rate of heat release Q in [W]. It is the source of the gas temperature rise, and the driving force behind the spreading of gas and smoke. The following temperature-time curve is valid for fire compartments up to 500m^2 of floor area. It is assumed that the fire load of the compartment is completely burnt out [7, Annex A]:

$$\Theta_g = 20 + 1325 * \left(1 - 0.324 * e^{-0.2t^*} - 0.204 * e^{-1.7t^*} - 0.472 * e^{-19t^*}\right) \quad [°\mathrm{C}] \qquad (6)$$

where $t^* = t * \Gamma$ and $\Gamma = (O/b)^2/(0.4/1160)^2$; O is the opening factor [m$^{1/2}$]; $b = (\rho * c * \lambda)^{1/2}$ in [J/m^{2}s$^{1/2}$K]. The maximum temperature Θ_{max} in the heating phase happens for $t^* = t^*_{max}$ with

$$t^*_{\max} = \max\left[\left(0.2 * 10^{-3} * q_{t,d} / O\right); t_{\lim}\right] \quad [\mathrm{h}] \qquad (7)$$

where $q_{t,d}$ is the design value of the fire load density related to the total surface area A_t of the enclosure.

4.3.2.1 Fire load densities

The design value of the fire load density $q_{f,d}$ is defined as [7]:

$$q_{f,d} = q_{f,k} * m * \delta_{q1} * \delta_{q2} * \delta_n \qquad [\mathrm{MJ/m^2}] \qquad (8)$$

where $q_{f,k}$ is the characteristic fire load density per unit floor area [MJ/m^2]; m is the combustion factor; δ_{q1} is taking into account the fire activation risk due to the size of the compartment and δ_{q2} the fire activation risk due to the type of occupancy; $\delta_n = \Sigma\delta_{ni}$ is taking into account the different active fire fighting measures i from Tables E.1 and E.2 [7]. These active measures are generally imposed for life safety reason.

Table E.1 — Factors δ_{q1}, δ_{q2}

Compartment floor area A_f [m²]	Danger of Fire Activation δ_{q1}	Danger of Fire Activation δ_{q2}	Examples of Occupancies
25	1,10	0,78	artgallery, museum, swimming pool
250	1,50	1,00	offices,residence, hotel, paper industry
2 500	1,90	1,22	manufactory for machinery & engines
5 000	2,00	1,44	chemical laboratory, painting workshop
10 000	2,13	1,66	manufactory of fireworks or paints

Table E.2 — Factors δ_{ni}

δ_{ni} Function of Active Fire Fighting Measures										
Automatic Fire Suppression		Automatic Fire Detection			Manual Fire Suppression					
Automatic Water Extinguishing System	Independent Water Supplies 0 | 1 | 2	Automatic fire Detection & Alarm by Heat	Automatic fire Detection & Alarm by Smoke	Automatic Alarm Transmission to Fire Brigade	Work Fire Brigade	Off Site Fire Brigade	Safe Access Routes	Fire Fighting Devices	Smoke Exhaust System
δ_{n1}	δ_{n2}	δ_{n3}	δ_{n4}	δ_{n5}	δ_{n6}	δ_{n7}	δ_{n8}	δ_{n9}	δ_{n10}
0,61	1,0 | 0,87 | 0,7	0,87 or 0,73		0,87	0,61 or 0,78		0,9 or 1 or 1,5	1,0 or 1,5	1,0 or 1,5

4.3.3 *Steel temperature development*

The calculation of the development of temperature fields in the cross section of a structural member exposed to fire involves solving Fourier's differential equation:

$$\frac{\partial}{\partial x}\left(\lambda_\Theta \frac{\partial \Theta}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda_\Theta \frac{\partial \Theta}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda_\Theta \frac{\partial \Theta}{\partial z}\right) + Q = \rho c_\Theta \frac{\partial \Theta}{\partial t} \qquad (7)$$

Q is the internal heat source and is equal to 0 in case of non-combustible walls. The boundary condition is expressed from the net heat flux $h_{net,d}$. Simple models for the steel temperature development calculation are based on the resolution of the equation (3) in the hypothesis of uniform temperature distribution in the cross section of the structural member. According to [3] the increase of temperature $\Delta\Theta_{a,t}$ in an unprotected steel member during a time interval Δt [s] should be determined from:

$$\Delta\Theta_{a,t} = k_{sh} * \frac{A_m / V}{c_a * \rho_a} \dot{h}_{net} * \Delta t \qquad [°\mathrm{C}] \qquad (8)$$

where k_{sh} is the correction factor for the shadow effect; A_m/V is the section factor for unprotected steel members [1/m]; ca is the specific heat of steel [J/kgK] and ρ_a is the unit mass of steel [kg/m3].

5 EXAMPLES

In this chapter the advantages of the application of the NFSC is shown on three examples: an open parking structure, realized 2004 in France and two multi-story buildings erected 2003 and 2007 in Luxembourg. According to the building use fire scenarios were determined, a realistic natural fire curve was calculated and the structure was verified for the elevated temperatures. Cost estimated for passive fire protection was generally based on [10]. The real savings may vary depending on the used fire protection products and the manufacturer.

5.1 *Parking "CARREFOUR", Aix en Provence, France*

Till 2004 it was impossible to built open car parks with unprotected steel members in France as no difference between open and closed car parks was made in the regulation from 1975. Due to of the research and fire tests done by CTICM, PAB and ARCELOR a design model based on real fire scenarios and realistic fire loads was developed [9].
The parking "Carrefour" is the first open car park realized with unprotected steel beams; it was the starting point for a new generation of parking structures in France and launched a large interest in this construction type.

Architect: Yves Melia –
Sud Architectes

Erection: Baudin-Châteauneuf

600 Places, 12400 m^2,
Grid 15 x 10m
Span composite slab a = 3,33m
(Cofraplus 60)
Primary steel beams:
HE 500A/550B S355,
Total length +/- 500m; +/- 93t
Secondary steel beams:
IPE 450/500 S355,
Total length +/- 4400m; +/- 370t

Circular composite Columns

Figure 5 : Parking « Carrefour »

Figure 6 : « Carrefour » - Composite Floor

The structure is designed to resist a real fire without any failure [9]. The esthetic and light structure with unprotected secondary and primary beams fulfills all architectural expectations.
Estimated saving for the secondary beams compared to spray-protected beams: approx. 30.000 €.
But a sprayed structure would never fulfill the architectural expectations!
Compared to fireproofing painted beams, the savings are approx. 160 000 € and 12.000 kg of paint.

With the realized solution no energy must spend on the maintenance of passive fire protection. The steel structure is easy to demount and to approx. 100% recyclable.

5.2 *Banque Populaire, Plateau de Kirchberg, Luxembourg*

Architect: Tatjana Fabeck, Thomas Krähenbühl
Design: Schroeder & Associés
Contractor: Hochtief Luxembourg

4 + 6 Storey office building 6400m^2, (+3 underground parking floors)
Hybrid Composite Cellular Beams HE 400B/M, S460, Span 16,8m
Composite Slab of 16cm (C30/37), Span 4,2m
Columns HD 400, S 355


Figure 7 : Banque Populaire

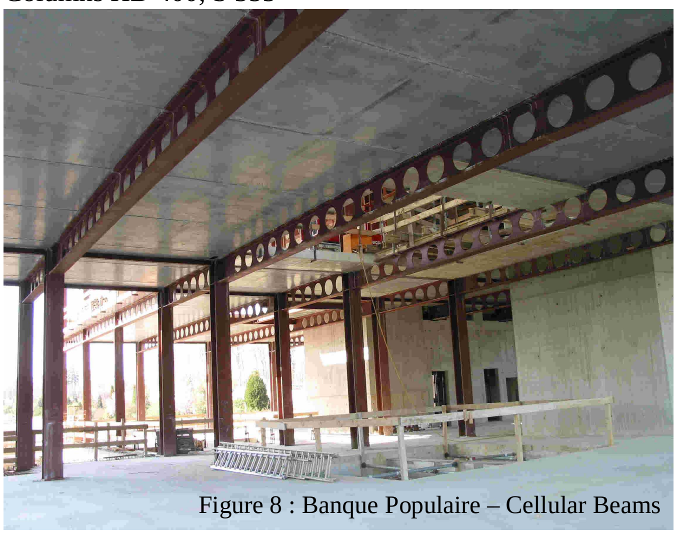
Figure 8 : Banque Populaire – Cellular Beams


Fig. 9 : Connection

Fire Safety Concept:

- Active fire fighting measures: Sprinklers with water reservoir 20m^3; Automatic alarm detection; Automatic alarm transmission to the fire brigade
- Connection with an extended end plate (Figure 9).

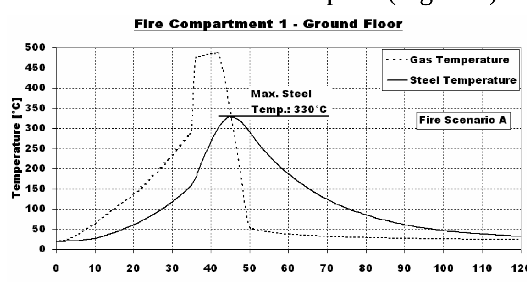

Fig. 10 : Banque Populaire - Natural Fire Curve

The natural fire curve of the most critical fire scenario is shown in Fig. 10. The maximum gas temperature is 490°C; the maximum steel temperature is less than 330°C. No significant reduction of the steel yield strength has to be done. With the application of the Natural Fire Safety Concept it was possible to use unprotected columns and unprotected beams. This amazing result is due to the implementation of the full set of active fire fighting measures. Compared to spray protected steel beams, the estimated savings are approx. 30.000€ and compared to fireproof painted beams approx. 66.000€ and 4000 kg of paint. A protection of the columns with fireproof board would cost additional approx. 70.000€ and 15000kg of board. The total estimated savings due to the application of the NFSC are approx. from 100.000€ to 136.000€.

5.3 *Centre Médical de la Clinique d'Eich, Luxembourg*

This building is an extension of the "Clinique d'Eich", Luxembourg. To respect the floor levels of the existing building and to guarantee a clear height of 2865mm the total slab thickness was restricted to 365mm. Therefore the Slim Floor system with composite beams was chosen. Due to the application of the NFSC it was possible to use unprotected columns and unprotected beams.

Architect: G + P MULLER Luxembourg
Design: Schroeder & Associés S.A.
Slim Floor Beams, Span 6,5m;
Fire Safety Concept with active fire fighting measures: Sprinklers, Automatic smoke ventilation, Automatic alarm detection, Automatic alarm transmission to the fire brigade

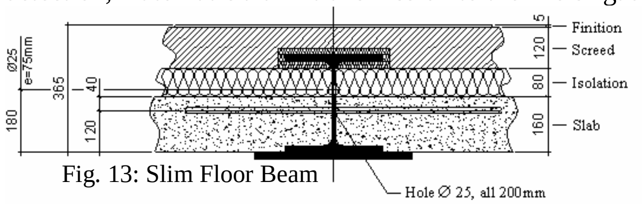

Fig. 13: Slim Floor Beam


Fig. 11 : Centre Médical

In the fire design situation, the load bearing capacity of the Slim Floor Beam (Fig. 13) is calculated by taking the composite action into account. The collaboration of the concrete slab and the SFB is achieved by additional transversal reinforcement (∅ 20, all 200mm). Compared to a conventional fire design procedure, protecting the columns and the lower flange of the SFB with fireproof board the estimated savings are approx. from 90.000€ to 100.000€ and approx. 20000kg.


Fig. 12 : Centre Médical – Slim Floor System

6 CONCLUSION

The EN procedure for providing structural safety in case of fire is quite realistic as it takes account of real fire characteristics and of existing active fire fighting measures. It consists in estimating the real behavior of a structure subjected to the natural fire which may arise under those real fire conditions. The consideration of real actions leads to real safety and also to optimized economy. Applying active fire fighting measures such as fire detection, alarm, automatic alarm transmission to the fire-fighters, smoke exhaust systems and sprinklers, provides protection to people that safety of people is ensured in an optimal way. The passive protection by insulation, needed in former times to guarantee the stability of the structure in case of fire, is strongly diminished and the budget dedicated to the fire safety will be used in a perfectly efficient way. Instead for paying for protection materials in order to fulfill ISO fire requirements of 90 minutes and more, this money shall be used for the installation of active fire safety measures. Indeed active fire safety produces real safety for people.
Steel is to 95% recyclable. In addition to the effective production process, steel constructions offer the advantage of prefabrication and short erection time.

7 REFERENCES

[1] ARBED S.A.; Constructing in steel: the ecological choice, Luxembourg 2002
[2] ECSC, ARBED S.A.; Natural Fire Safety Concept, Luxembourg 2001
[3] International Iron and Steel Institute; Fire Engineering Design for Steel Structures, Brussels 1993
[4] J.-B. Schleich; Einwirkungen auf Tragwerke im Brandfall – EC 1, ISFSSS Cologne 2003
[5] J.-B. Schleich; Globales Brandsicherheitskonzept, Stahlbau 67 (1998),
[6] CEN; EN 1990, Basis of structural design, CEN Central Secretariat, Brussels, 2002
[7] CEN; EN 1991-1-2, Actions on Structures, Part 1-2–Actions on structures exposed to fire, CEN Central Secretariat, Brussels, 2002
[8] CEN; EN 1993, Design of steel structures-Part 1-2: General rules-Structural fire design, CEN Central Secretariat, Brussels, 2005
[9] Fraud, Zhao, Joyeux, Kruppa; Guide pour la vérification du comportement au feu de Parcs de stationnement largement ventiles en superstructure métallique, CTICM, 2003
[10] UNTEC, Groupe Métal, Arcelor; Economie et solutions acier, Carnets De L'Acier, 2006

Sustainable concrete production

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ABSTRACT: Concrete is the most widely produced construction material, and large quantities of waste materials from construction as well as from other industries can be re-used in its production. The paper presents results of experimental investigations of the behavior of concrete containing crushed waste concrete (rubble) as aggregate and the behavior of concrete containing waste wash water from ready mix concrete production. The influence of different additions to concrete upon various mechanical properties as well as durability of such concrete are presented. The results show that both recycled materials investigated have a potential to be used in concrete production.

1 INTRODUCTION

Increasing environmental awareness has forced the industries and businesses to start assessing the impact of their activities upon the environment. When the concept of sustainable development (Our common future 1987) was introduced, attention was gradually being focused on issues related to natural sources depletion and environment degradation. Environmental performance has become a key issue, and many companies have begun to investigate ways to minimize the effects on the environment of their activities (EPA 2006).

Building materials production offers a wide range of possibilities for recycling of industrial waste. Waste generated in construction as well as in other industry types can be used instead of virgin raw materials required to produce construction materials. This leads to conservation of natural resources as well as to reduced need for space required to landfill the waste, and is therefore in line with the sustainable development of the natural and built environment.

One of the possibilities of recycling waste materials is to use certain types of industrial and demolition waste, such as slag, glass, crushed brick or concrete rubble, as a substitute of natural aggregate in concrete, the most widely used construction material. Another way is to re-use waste wash water that is being produced during concrete production as mixing water for concrete. Cement can be partly substituted by supplementary cementing materials that originate from secondary sources.

Using secondary materials in concrete, however, poses certain challenges. During its use in structure, concrete has to exhibit performance level which is defined in the design phase. If constituent materials, i.e. cement, aggregate, water and admixtures, are replaced by secondary raw materials, the influence of these materials has to be determined prior to the application of such concrete in practice. Each waste material that shows a potential to replace a virgin constituent material in concrete has to be carefully tested in laboratory as well as in field conditions.

The following cases have been investigated within the scope of this paper:

- behavior of concrete containing crushed waste concrete (rubble) as aggregate, and
- behavior of concrete containing waste wash water from concrete production.

Being a preliminary study, only laboratory testing was carried out.

2 SUBSTITUTION OF NATURAL AGGREGATE WITH RECYCLED RUBBLE-BASED AGGREGATE

Concrete is a composite material consisting of aggregate and binding material. Approximately 60-70% of the concrete volume is occupied by aggregate, usually of mineral origin.

Based on the source material, secondary aggregates originating from construction and demolition (C&D) waste can be distinguished as concrete aggregate, masonry aggregate, mixed aggregate and asphalt aggregate (Hendriks 2000). The aim of the work presented in this paper was to use concrete rubble-based aggregate in concrete, where all constituent materials (including rubble) originate from local sources.

Level of impurities in the source material (parent concrete) is one of the most influential factors affecting the successful use of such aggregate. Wood, sulphates originating from waste plaster, soil, aluminium, chlorides, plastic and alkali reactive stone are potentially harmful components of the source material that pose physical and chemical threat to the quality of the structure (Hendriks 2000). Further, rubble-based concrete contains larger quantities of fine particles that arise from crushing the cement paste of the parent concrete. These fine particles may affect the properties of both fresh and hardened concrete.

For the purpose of the study, the source material for rubble-based aggregate was carefully monitored so that the level of impurities was reduced to a minimum. Waste concrete was then crushed to smaller particles with the help of a jaw crusher and sieved to obtain fine (particle size range 0/4 mm) and coarse aggregate (of particle size ranges 4/8 and 8/16 mm) for concrete.

Mechanical and durability properties of concrete where only part of the aggregate was substituted by crushed waste concrete were determined and compared to properties of a) reference concrete containing only natural aggregate and b) concrete prepared with recycled aggregate only. Five concrete mixtures were prepared and labelled as

A – contains natural aggregate only (reference concrete)

B – contains recycled fine aggregate and natural coarse aggregate (both particle size ranges)

C – contains natural fine aggregate, recycled coarse aggregate (particle size range 4/8 mm) and natural coarse aggregate (particle size range 8/16 mm)

D – contains natural fine aggregate, natural coarse aggregate (particle size range 4/8 mm) and recycled coarse aggregate (particle size range 8/16 mm)

E – contains both fine and coarse recycled aggregate

Locally obtainable constituent materials were employed. Cement of CEM II/A-S 42.5R type was supplied and produced by the largest Slovenian cement producer. One of the most frequently used regional river gravels was employed as natural aggregate. All concrete types contained the same amount of cement and superplasticizer (SP). Composition of the concrete mixtures prepared is presented in Table 1.

Table 1. Composition of concrete prepared with natural and recycled aggregate.

				per m^3 concrete			
Label	Aggregate (kg)			cement (kg)	water (kg)	SP (l)	w/c
	fine	coarse					
		4/8 mm	8/16mm				
A	854	387	696	360	169.2	6.5	0.43
B	**733**	331	546	360	270.0	6.5	0.74
C	793	**334**	646	360	219.6	6.5	0.62
D	822	372	**602**	360	195.8	6.5	0.64
E	**630**	**283**	**492**	360	320.0	6.5	0.90

It is expected that the aggregate origin will affect more significantly the fine aggregate fraction. Sieve analysis was therefore carried out for both natural and recycled fine aggregate, and the results are presented in Figure 1. It can be seen that rubble-based fine aggrregate contains a larger proportion of fine particles; it contained more particles under 0.125 mm than natural material, and less particles with size ranging between 0.25 and 2 mm.

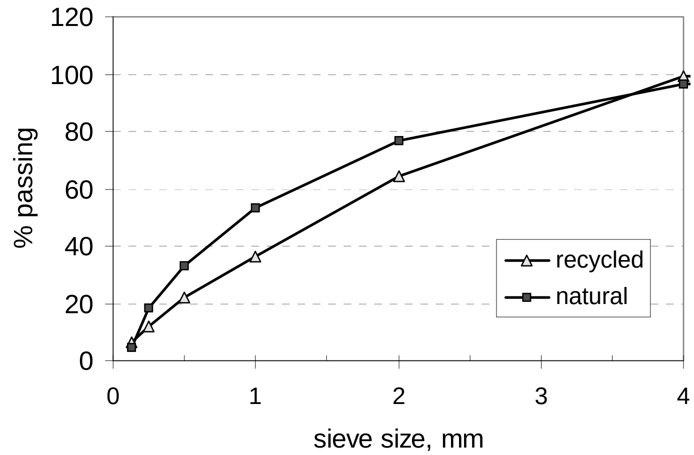

Figure 1. Sieve analysis of the fine aggregate for natural and recycled aggregate employed.

The level of water was adjusted to achieve the same level of fresh concrete consistency for all concrete types investigated. The results presented in Table 1 show that the largest amount of water was added when fine aggregate is substituted by the recycled material.

The largest differences in particle sizes between natural and recycled aggregate were observed for the fine aggregate. Figure 1 shows the sieve analysis of fine aggregate for both aggregate types.

Fresh concrete properties, slump, air content and density were measured in accordance with the standards EN 12350-2, 7 and 3. The values obtained are presented in Table 2. It can be observed that the air content increased when fine aggregate contained recycled aggregate, and density was decreased accordingly. Slump ranged between 50 and 90 mm, as designed, for all concrete mixtures prepared. Values for selected mechanical properties of hardened concrete containing recycled aggregate are presented in Table 3. Standard procedures EN 12390-3 and 11 were used to measure the compressive strength and water-tightness.

Table 2. Fresh concrete properties for different concrete mixtures containing recycled aggregate.

label	slump, mm	w/c	air content, %	unit weight, kg/m^3
A	80	0.43	1.7	2444
B	50	0.74	2.7	2275
C	90	0.62	1.9	2375
D	60	0.64	1.9	2338
E	70	0.90	3.4	2110

Table 3. Influence of recycled aggregate upon hardened concrete properties.

label	comp.strength @ 28 days, MPa	depth of water penetration, mm
A	53.3	32
B	31.1	25
C	44.9	15
D	48.8	13
E	31.3	27

Depth of water penetration is an indicator for the permeability of concrete; the larger the depth, the more permeable is the porous material. Despite a significant increase in water to cement ratio, w/c, depth of water penetration decreased for concrete containing coarse recycled aggregate. This trend was observed for both aggregate particle size ranges. Penetration depth of concrete containing fine recycled aggregate (type B and E) was only slightly reduced when compared to the reference concrete (no recycled aggregate). This could be explained by the presence of increased quantity of fine particles in the fine recycled aggregate.

Compressive strength was significantly decreased when recycled aggregate was used. This can be predominantly attributed to the increased water to cement ratio. It is interesting to note, however, that the strength of concrete containing only recycled aggregate (E) was practically equal to the strength of concrete containing recycled fine aggregate only (B).

The obtained results show that the behavior of concrete types C and D that both contain recycled coarse aggregate of different particle size range is very similar for all properties investigated.

3 USE OF RECYCLED WATER IN CONCRETE

In the production of concrete, large amounts of water are used for washing the mixer, the mixing drums of truck mixers or agitators and other equipment in ready mix concrete plants. Typically, 100 l of wastewater is generated per cubic meter of concrete in ready-mixed production (Chini 2001). After the washing process is completed, the wash water contaminated predominantly with fine concrete particles is usually disposed. Prior to disposal, water is retained in sedimentation basins in order to reduce the level of solid particles.

Large quantities of fresh tap water are therefore used and consequently disposed of in concrete production. Fresh water resources could be preserved if this water could be re-used. Slovenia has recently imposed an increase of tax for disposing waste water, therefore several concrete mixing plants have shown interest in improving the sustainability of their production processes.

If quantities of solids are not too high, the waste wash water can replace tap water as one of the constituent materials in the concrete mixture. Ready mix concrete plants often avoid using ready-mix truck wash water in the production of fresh concrete, partly due to limited data available (Sandrolini 2001). Local source materials should be used in preliminary testing if reliable concrete production is to be ensured.

In order to investigate the possibility of re-using waste wash water, a comparative study of the influence of recycled water on the concrete properties was carried out. Concrete samples were produced in three different concrete batching plants. For each plant, properties of reference concrete (prepared with tap water) were compared to properites of concrete prepared with recycled water. In each plant, routinely used local aggregate was employed in the preparation of mixes.

The same amount of water was used in the preparation of both types of samples. Chemical analysis of waste wash water from one of the plants is presented in Table 4. Based on the recommendations of the EN 1008 and the results obtained for the density of recycled water, mass of solid material in recycled water was estimated to be 0.057 kg/l. Additional mass od solid material in the concrete resulting from the use of water recovered from processes in the concrete industry is therefore below the limitation imposed by EN 1008 (1%).

Table 4. Analysis of recycled water.

type of water	sedimentation, ml sediment / 80 ml sample	pH	Cl- , mg/l	SO4 2- , mg/l	density, kg/l
tap	-	7.94	10.64	22.43	1.00
recycled	37	11.42	6.91	10.70	1.03

Composition of concrete produced at the selected concrete plant is presented in Table 5. Maximum aggregate size of 32 mm was selected. Designed compressive strength and water to cement ratio were 30 MPa and 0.40, respectively. Cement type CEM I 42.5 R was employed. 2% of superplasticizer and 0.1% of the air entraining agent (with respect to the cement mass) was added to the mixture. The same type of superplasticizing agent was employed as in concrete containing recycled aggregate. Slump, air content and fresh concrete density were measured according to the standards EN 12350-2, 7 and 3. Results for fresh concrete properties collected in Table 6 indicate that the replacement of tap water with recycled water resulted in increased consistency of fresh concrete, i.e. decreased slump, and decreased air content. This can be attributed to the increased level of fine particles contained in the water used in the preparation of concrete mixture.

Both compressive strength and watertightness, i.e. depth of water penetration, were measured according to EN 12390-3 and 11. The results are collected in Table 7. Compressive strength of both types of concrete was measured at 3, 7 and 28 days. At 28 days, the loss of strength due to the replacement of tap water with recyled wash water was 10%. Use of recycled wash water leads to significant increase of watertightness, or, in other words, depth of water penetration reduced by 38% when recycled wash water was employed. Again, this happens probably due to the presence of fine particles in waste water.

Table 5. Composition of concrete prepared with tap and recycled wash water.

type of water	aggregate, kg		cement, kg	water, kg	SP, l	AE, l
	fine	coarse				
tap	801	906	388	159	7.76	2.13
recycled	796	903	387	155	7.80	2.16

SP = superplasticizer, AE = air entraining agent

Table 6. Fresh concrete properties.

type of water	slump, mm	w/c	air content, %	unit weight, kg/m^3	water compliance with EN 1008
tap	130	0.41	7.0	2263	yes
recycled	40	0.40	4.8	2325	yes

Table 7. Properties of hardened concrete prepared with tap and recycled water.

type of water	compressive strength, MPa			water-tightness, mm
	@ 3 days	@ 7 days	@ 28 days	
tap	28.6	34.6	42.6	25.3
recycled	34.9	40.8	47.5	15.7

4 CONCLUDING REMARKS

One of the possibilities to implement the principles of sustainable development into construction is to recycle construction materials. The largest benefit is obtained if the most widely used materials, such as concrete or its constituents, are recycled. A study dealing with the possibilities of recycling concrete rubble and waste water that results form the concrete production was therefore initiated. The obtained results show that both recycled materials investigated can be used in concrete production.

Concrete crushed into appropriate particle sizes has a potential to be used as aggregate in concrete instead of virgin stone material. However, in order to ensure the performance of concrete placed in a structure, the influence of such secondary material upon concrete properties has to be assessed prior to its use in practice. The results presented show that substitution of fine aggregate has the greatest influence on the concrete properties. This is probably due to the large content of fine particles present in recycled fine aggregate. Chemical composition of recycled aggregate, especially its hardened cement paste content, has also large influence upon concrete behaviour.

Waste wash water that would otherwise had to be disposed can be used as mixing water in the preparation of concrete. The results of the investigations show that the influence of waste water on both fresh concrete and mechanical properties is minute.

If use of waste water is to be incorporated into the concrete production technology, confidence into the waste water composition should be established by its monitoring. Maximum permissible levels of individual potentially harmful components have to be known, and chemical composition fluctuations should be kept within these pre-determined intervals. Successful use of waste wash water leads to preserving precious natural resources of drinking water, therefore the producers should be encouraged to recycle their waste wash water in several ways.

REFERENCES

Chini, A. R. et al. 2001. Reuse of wastewater generated at concrete plants in Florida in the production of fresh concrete. *Magazine of concrete research*, 53: 311-319.

EPA 2006. U.S. Environmental Protection Agency and Science Applications International Corporation. LCAccess – LCA 101 (available at http://www.epa.gov/nrmrl/lcaccess/)

Hendriks, C.F. & Pietersen, H.S. 2000. Sustainable raw materals: construction and demolition waste, State of the art report of RILEM TC 165-SRM, No.22

Our common future 1987. Oxford Press

Samarin, A. 1999. Wastes in Concrete: Converting liabilities into assets, In: Proceedings of the International Seminar, University of Dundee, Scotland, GB, Thomas Telford, pp.1-21

Sandrolini, F. & Franzoni, E. 2001. Waste wash water recycling in ready-mixed concrete plants. *Cement and concrete research*, 31: 485-489.

Šelih, J. et al. 2004. The use of waste materials in building and civil engineering. *Materials and technologies*, 38: 79-86.

General issues of construction materials recycling in USA

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ABSTRACT: Nearly all building materials have the potential for reuse following their initial useful life. Although reuse possibilities are available for building materials following demolition, deconstruction maximizes this potential because it allows these materials to be recovered with the least possible amount of damage. Additionally, the organizational nature of deconstruction involves sorting separate materials, which further facilitates reuse opportunities. Wood, steel, concrete, asphalt roofing, brick, plastics, and drywall all have high reuse potential. This paper evaluates the existing practice of reuse of construction materials in the USA and recommends suggestions for increasing construction materials reuse.

1 INTRODUCTION

The demolition of building structures produces enormous amounts of materials that in most countries results in a significant waste stream. Construction and Demolition waste (C&D) include waste from the construction, renovation, and removal of buildings; from the construction and demolition of roads, bridges, and other nonbuilding structures; and from the clearing of rocks, trees, and dirt. Quantifying the annual C&D waste in the US is an inexact science. Building related C&D waste was estimated to be 143.3 million metric tons in 2000 (Chini and Bruening, 2005). This estimate was achieved by multiplying number of buildings being constructed or demolished by amounts of waste estimated to be generated per square foot. Renovation figures were derived from estimates of consumer and business spending on specific remodeling and renovation activities (see Table 1). Franklin and Associates (1998) estimates that 35 to 45 percent of this debris is sent to Municipal Solid Waste (MSW) landfills or unpermitted landfills and 20 to 30 percent is reused or recycled (see Table 2).

Table 1 Summary of estimated building-related C&D debris generation, 2000
(Million Metric Tons)

	Residential	**Non-residential**	**Totals**
Construction	8.8 (14%)	6.0 (7%)	**14.8** (10%)
Renovation	34.5 (56%)	30.2 (37%)	**64.7** (45%)
Demolition	17.9 (30%)	45.9 (56%)	**63.8** (45%)
Totals	**61.2** (43%)	**82.1** (57%)	**143.3**

Table 2 Estimated quantities of materials bound for C&D landfills, MSW and unpermitted landfills, or recovery (Million Metric Tons).

	C&D Landfills (40%)	MSW/Unpermitted Landfills (35%)	Recovered (25%)	Total (100%)
Residential				
demolition	7.2	6.3	4.5	**18.0**
renovation	13.7	12.1	8.6	**34.4**
construction	3.5	3.1	2.2	**8.8**
Non-Residential				
demolition	18.4	16.1	11.5	**46.0**
renovation	12.1	10.4	7.6	**30.1**
construction	2.4	2.2	1.4	**6.0**
Total	**57.3**	**50.2**	**35.8**	**143.3**

Deconstruction may be defined as the disassembly of structures for the purpose of reusing components and building materials. The primary intent is to divert the maximum amount of building materials from the waste stream. Top priority is placed on the direct reuse of materials in new or existing structures. Immediate reuse allows the materials to retain their current economic value.

The next desirable option for waste is to recycle. In a perfect world, the term recycling would describe a process in which raw materials achieve an endless useful life. Each conversion for reuse of the material would have future reuse possibilities designed in. It is true that nothing can be used forever. The passing of time eventually renders all materials useless. However, the concept of an endless useful life potential for raw materials is achievable. “Closed-loop” recycling should be the end goal of the recycling industry in order to maximize the usefulness of virgin materials and minimize the necessity to extract them.

Currently, the recycling of materials frequently does not allow for future use of the material after the initial conversion. When lumber extracted from deconstruction or demolition site is ground into mulch for landscaping, the useful life of the material is extended and that quantity of virgin materials is preserved. However, the possibility for future use after that is virtually eliminated. Processes such as this, which we usually call recycling, are not actually recycling at all. The process of reducing a raw material’s quality, potential for future uses, and economic value, is called downcycling. The process of reusing a material for similar uses, thus maintaining the possibility for reuse again later, is recycling. The process of increasing the material’s quality, potential for future use, and economic value is called upcycling.

Nearly all building materials have the potential for reuse following their initial useful life.
Although reuse possibilities are available for building materials following demolition, deconstruction maximizes this potential because it allows these materials to be recovered with the least possible amount of damage and contamination. Additionally, the organizational nature of deconstruction involves sorting separate materials, which further facilitates reuse opportunities. Wood, steel, concrete, asphalt roofing shingles, brick, plastics, and drywall all have high reuse potential. A close-up of each of these materials follows.

2 RECYCLED AGGREGATE

Recycled aggregate is produced by crushing concrete and asphalt pavement to reclaim the aggregate. The primary market for recycled aggregate is road base. More than 91 MMT of worn-out asphalt pavements are recovered annually. About 80 percent of the recovered material is currently recycled, and the remaining 20% is land filled. One-third of the recycled material is used as aggregates for new asphalt hot mixes and the remaining two-third is used as road base (Kelly, 1998).

Total building related and infrastructural C&D waste concrete generated annually in US is estimated to be about 182 MMT (Sandler, 2003). It is estimated that about 50 percent (91 MMT) of waste concrete is recycled annually into usable aggregates. This is roughly 5 percent of 1.8 billion metric tons total aggregates market. The rest is supplied by virgin aggregates from natural sources. An estimated 68 per cent of aggregate recycled from concrete is used as road base and the remainder is used for new concrete (6 percent), asphalt hot mixes (9 percent), and low value products like general fill (Deal, 1997). The low usage rate of recycled concrete aggregate (RCA) in new concrete and asphalt hot mixes (15 percent) compared to the higher usage rates in lower valued products is related to real and perceived quality issues. Many State agencies have allowed use of RCA mostly as road base materials and not for high-quality uses such as road surfacing.

Concrete can be recycled by hauling the concrete debris to a permanent recycling facility for crushing and screening or it can be crushed and screened at the demolition site where the aggregate is reused when it is processed. The latter approach is preferred because it reduces transportation costs and energy use due to hauling materials. Some States convert existing worn-out concrete roads to rubble-in-place. The old concrete surface is broken up and compacted, and asphalt pavement is placed over the enhanced base.

For concrete recycling to be profitable, transportation costs need to be kept low, which forces the market to be urban oriented. The availability of feedstock into recycling plants depends on the amount of demolition taking place, which is much higher within older, larger cities. Recycling concrete plants often have the opportunity to charge a fee for accepting concrete debris, especially where fees for depositing materials into landfills are high. This added revenue can compensate for a lower market price for recycled aggregate products.

The future of recycled aggregates will be driven by higher landfill costs, greater product acceptance, government recycling mandates, and a large stock of existing roads and buildings to be demolished. Favorable in-service experience with recycled aggregates and development of specifications and guidelines for their use are necessary for recycled aggregate acceptance. A sustainable recycling aggregate industry requires sufficient raw materials, favorable transportation distances, product acceptance and limited landfill space.

3 ASPHALT ROOFING SHINGLES RECYCLING

Shingles in the waste stream are tear-offs from re-roof jobs, demolition debris, tabs that are cut out to shape the new shingles for assembly, and discarded new shingles that did not meet quality standards. Asphalt shingle scrap can be used in asphalt pavement, aggregate base and subbase, cold patch for potholes, and new roofing. In U.S., approximately 10 MMT of waste asphalt roofing shingles (ARS) are generated per year. Re-roofing jobs account for 9 MMT and manufacturing scrap generates another 1 MMT (CIWMB, Shingles).

ARS are made of asphalt cement (19 to 36 percent), mineral filler (limestone, silica - 8 to 40 percent), mineral granules (ceramic-coated natural rock - 20 to 38 percent), and felt backing (organic or fiberglass - 2 to 15 percent). Between 1963 and 1977, three of the largest shingle manufacturers used asbestos in their fiber mat of their shingles. The average asbestos content was 2 percent in 1963 and 0.00016 per cent in 1973. Due to the practice of covering a worn out roof with new shingles, there may continue to be a very small amount of asbestos in the shingle waste stream until about 2016 (some shingles last up to 20 years). Although only a small percentage of shingle production over a limited number of years involved asbestos, asbestos-containing roofing materials is a potential hazard that recyclers must face (NAHB, 2007).

Scraps produced during the manufacturing process has a uniform content, whereas tear-off waste may be composed of varying composition and has been exposed to ultraviolet sunlight. Many State departments of transportation have specifications that allow the use of recycled shingles in pavement materials. Some do not allow the use of tear-off scrap for potential asbestos-content and content and condition variability.
The factors that affect roofer's disposal choices between recycling yards and landfills are transportation costs and disposal fees. Recyclers typically charge about $30 per ton to cover processing costs. The differential between the recycler's charge and the landfill tip fee must be large enough to provide an economic incentive to roofers to avoid landfill disposal.

4 WOOD RECYCLING

According to Falk and Mckeever (2004) an estimated 25.2 MMT of demolition waste and 10.5 MMT of construction waste for total of 35.7 MMT of C&D waste wood was generated in 2002. Their study also concluded that about 18.4 MMT or approximately 50% of the generated waste was recoverable. With the exception of scrap steel, wood products have the highest recoverability level of any building materials. This is due to the large amount of recoverable wood in the deconstruction and demolition market. Additionally, the ways in which wood can be reused are numerous. Wood products can be recycled for direct reuse in similar applications, they can be downcycled into mulch, or they can be upcycled into more valuable items, such as custom cabinetry or furniture.

Many wood products can be recovered and reused directly, with little or no processing necessary. Currently, recovered structural timbers are in high demand in the United States because of their lack of availability from any other source. Virgin stocks were overexploited during the years of heavy logging and have yet to recover. People value the timbers for their aesthetic quality and historical significance. Additionally, dimension framing lumber can be recovered and reused as is. The market for recycled dimension lumber is still a fledgling industry. The reuse applications for recovered lumber are currently limited due to a lack of standardized grading requirements. This should change with the establishment of grading requirements. Once the structural uses of recovered dimension lumber are established, the demand will increase exponentially. Reusing recovered wood products in similar applications extends the lifecycle of the product because it maintains the potential for further recycling down the line.

Wood products can be upcycled into more valuable products. This is often the ideal situation because it maintains the recyclability of the product while increasing its economic potential. An example of upcycling wood products includes the conversion of recovered framing lumber into custom cabinetry, furniture, or wood flooring.

Downcycling of wood products involves decreasing the future recyclability and economic potential of the wood. For example, one option for wood waste is to use it as a feedstock for engineered wood products such as, particle boards or oriented strand boards. Sometimes scrap wood from demolition is sent through a grinder and turned into mulch. This eliminates the possibility of further recycling of the wood at a later date and diminishes its economic value. The markets for downcycled wood products include mulch, fibers for manufacturing, animal bedding, and biomass.

Downcycling of wood products should be the last option when considering reuse possibilities because it degrades the material. However, downcycling is an important alternative in the recycling industry. Many used wood products have no available reuse options. Downcycling this wood serves to divert it from the waste stream and create supply for the mulch, biomass, and animal bedding markets.

Wood treated with chromated copper arsenate (CCA) for preservation against insects may need to be managed using alternative methods. The use of CCA treated wood products in residential applications has been banned by the EPA and regulations are being developed for the handling of treated wood and its disposal.

5 STEEL RECYCLING

The North American steel industry is far ahead of any other building material industry in its use of recycling to conserve raw materials and create economic opportunity. "Each year, steel recycling saves the energy equivalent to electrically power about one-fifth of the households in the United States for one year and every ton of steel recycled saves 2,500 pounds of iron ore, 1,400 pounds of coal, and 120 pounds of limestone" (Steel Recycling Institute). The steel industry's overall recycling rate is nearly 75%. This includes the recycling of cans, automobiles, appliances, construction materials, and many other steel products. All new steel products contain recycled steel. In 2005, almost 70 MMT of steel were recycled or exported for recycling (Steel Recycling Institute).

There are two processes for making steel. The Basic Oxygen Furnace process, which is used to produce the steel needed for packaging, car bodies, appliances and steel framing, used a minimum of 31% recycled steel in 2005. The Electric Arc Furnace process, which is used to produce steel shapes such as railroad ties and bridge spans, used nearly 95% recycled steel (Steel Recycling Institute). According to the Steel Recycling Institute 97.5 percent of structural beams and plates and 65 percent of reinforcing steel were recycled in 2005.

6 DRYWALL RECYCLING

Drywall, also referred to as gypsum board is the principal material used in the U.S. for interior applications. It is made of a sheet of gypsum covered on both sides with a paper facing and a paperboard backing. The U.S. produces about 13.7 MMT of new drywall per year. Most drywall waste is generated from renovation (10 MMT), new construction (1.5 MMT), demolition (0.9 MMT), and manufacturing (0.3 MMT) (Sandler, 2003).

Scrap gypsum drywall is currently being recycled in several applications including:

- The manufacture of new drywall
- Use as an ingredient in the production of cement
- Application to soils and crops to improve soil drainage and plant growth
- A major ingredient in the production of fertilizer products
- An additive to composting operations

In recent years, scrap drywall from new construction is separated and processed at the project site using a mobile grinder and used as a soil amendment or a plant nutrient. This approach may be feasible when the soils and grass species show a benefit from the application of gypsum. This recycling technique offers a potential economic benefit when the cost to process and land apply the ground drywall at the construction site is less than the cost to store, haul and dispose of the drywall.

The presence of gypsum drywall in landfills has been linked to the production of hydrogen sulfide (H2S). H2S has a foul, rotten-egg odor that has caused numerous complaints at landfills around in U.S. and Canada. As a result, several communities in Canada do not accept drywall at landfills and, several locations in U.S. are considering placing restrictions on the amount of drywall that may be land disposed.

Despite its successful use in many locations, most drywall is still disposed in landfills due to challenges in collection and separation and low landfill disposal fees (CMRA, Drywall).

7 BRICK RECYCLING

The preferred method of recycling used bricks is to remove them undamaged and reuse them directly. The only current method used commercially to enable used bricks to be made suitable for reuse in their original form involves cleaning the old mortar from the bricks by hand. A small blunt hand axe can be used to knock the mortar from the bricks. The problem with this is that it is extremely difficult to remove modern Portland cement based mortar from bricks using the technique described above. Thus only old bricks are generally cleaned and recycled by this method. There are however, studies in progress involving the use of pressure waves to break the bond between the mortar and the bricks. This may become a viable solution and create more brick recycling opportunities in the near future.

There are currently studies ongoing concerning the use of crushed brick in road base. The results have been inconclusive to this point.

8 PLASTICS RECYCLING

According to the 2000 State of Plastics Recycling, nearly 1700 companies handling and reclaiming post-consumer plastics were in business in 1999. This was nearly six times greater than the 300 companies in business in 1986. The primary market for recycled PET bottles continues to be fiber for carpet and textiles and the primary market for recycled HDPE is bottles. However, a recently updated *Recycled Plastics Products Source Book* lists over 1,300 plastic products from recycled content, including waterproof paper products and plastic lumber for structural applications. New ASTM (American Society for Testing and Materials) standards are paving the way for plastic lumber that could be used in framing, railroad ties, and marine pilings (State of Plastics Recycling). The use of recycled plastics for such applications could mean longer life and less maintenance, which translated to lower cost over the life of the product.

There is however a need to increase the reuse and recycling rates for plastics, which are currently much lower than other major construction materials steel, concrete, and wood. The construction industry uses 60 per cent of global PVC, which is difficult to recycle and can contaminate recycling of other commonly recycled plastics. There was only a 1.7% increase in the pounds of plastic collected in 2005 (0.96 MMT) compared with that of 2004 (0.87 MMT) (State of Plastics Recycling).

9 SUMMARY AND RECOMMENDATIONS

Table 3 summarizes estimated waste due to building and infrastructure related construction and demolition as well as municipal solid waste. The table also shows estimated weight of recovered materials. As Table 3 shows only concrete and steel have a recovery rate of 50 per cent or above. The recovery rate for other materials is not significant, but it is increasing due to rising cost of landfilling waste, stringent new government regulations, and a steady growing concern for the environment. Many demolition contactors are integrating recycling as a side business. According to one estimate in 2005, there were about 3500 C&D recycling facilities in U.S. (Taylor 1, 2005).

Table 3 C&D waste generation and recovery (MMT)

Material	Building C&D Waste	Infrastructure C& D Waste	Steel Products	Municipal Solid Waste	Re-covered
Concrete	55	127	-	-	91
Wood	36	-	-	27	10
Drywall	13	-	-	-	2
Roofing	10	-	-	-	NA
Steel	9	12	59	13	70
Bricks	4	-	-	-	NA
Plastics	4	-	-	24.3	1

NA: the recovered weight is Not Available

Several of the states have established regulations that require a minimum recycling rate for C&D waste. Chicago recently adopted an ordinance requiring a certain percentage of construction and demolition waste to be recycled — 25 percent for projects that had a permit issued in 2007, and 50 percent if the permit is issued in 2008 (Martin, 2007). In Oregon, the city of Portland requires a 75 per cent recycling rate on all C&D projects exceeding $50,000. In addition to $24 per metric ton tipping fee, a $38 per metric ton tax is imposed on all landfill debris (Taylor, 2005a). In Sonoma County, California C&D waste loads that have not been sorted for recyclables must pay a 25 percent surcharge for the county to handle resorting.

According to the National Demolition Association (NDA) only four materials – concrete, metal, high quality lumber, and wood have current market value. NDA suggests that the federal government establish specifications and purchasing guidelines for each recovered material; take a leading role in promoting the development of new technologies and processes that will produce durable, economical, high quality recycled products ; provide tax incentives for end users of the recycled products; and develop national inspection standards for recycling facilities (Taylor, 2005b).

The future of recycled materials will be driven by higher landfill costs, greater product acceptance, and government recycling mandates. Favorable in-service experience with recycled materials and development of specifications and guidelines for their use are necessary for recycled materials acceptance. A sustainable recycling material industry requires sufficient raw materials, favorable transportation distances, product acceptance and limited landfill space.

10 REFERENCES

California Integrated Waste Management Board Fact Sheet on Drywall Recycling, http://www.ciwmb.ca.gov/ConDemo/Wallboard/

California Integrated Waste Management Board, Fact Sheet on Asphalt Roofing Shingles Recycling, http://www.ciwmb.ca.gov/ConDemo/Shingles/

Chini, A.R. and Bruening, S., Deconstruction and Materials Reuse in the United States, in Deconstruction and Materials Reuse – An International Overview, A.R. Chini, Editor, CIB Publication 300, March 2005.

Construction Materials Recycling Association, Can Gypsum Drywall be Recycled? http://www.drywallrecycling.org/

Deal, T.A.,1997, What it costs to recycle concrete: C&D Debris Recycling, September/October. P. 10-13.

Falk, Robert H. and McKeever, David B., Recovering Wood for Reuse and Recycling- A United States Perspective, Proceedings of European COST E31 Conference, 22-24 April 2004, Thessaloniki

Franklin Associates, Characterization of Building-Related Construction and Demolition Debris in the U.S.,A report to the US Environmental Protection Agency Office of Solid Waste and Energy Response, Washington, D.C., 1998.

Kelly, T.D.., 1998, The substitution of crushed cement concrete for constriction aggregates: U.S. Geological Survey Circular 1177, 15 p., http://greenwood.cr.usgs.gov/pub/circulars/c1177/

Martin, Brett, A Green Look at Masonry, Masonry Magazine, April 2007 http://www.masonrymagazine.com/4-07/green.html

National Association of Home Builders Research Center, 2007, From Roofs to Roads, http://www.epa.gov/epaoswer/non-hw/debris-new/pubs/roof_br.pdf

Sandler, Ken, Analyzing What's Recyclable in C&D Debris, BioCycle, November 2003, PP 51-54.

Taylor, Michael R., Moving and Shaking, Waste Age, October 2005a, pp. 34-40.

Taylor, Michael R., Resources in the Rubble, Recycling Today, February 2005b, PP 62-64.

Eco-concrete: preliminary studies for concretes based on hydraulic lime

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ABSTRACT: Concrete is a major worldwide building material, in which Portland cement is the usual binder. Taking into account environmental factors in cement production, especially concerning CO_2 emissions and energy consumption, this work aims at the development of concrete with a hydraulic lime binder. Furhermore, in order to increase mechanical strength, particularly at early ages, pozzolanic materials were added. In this preliminary study, compositions with different percentages of hydraulic lime were tested and a pozzolanic material, a residue from expanded clay production, was used. Variations in percentage of pozzolan, water/cement ratio and conditioning were carried out. Concrete specimens were tested for mechanical strength at various ages. This paper presents the results of this initial testing campaign, concluding on the feasibility of the use of hydraulic lime for concrete production and potential applications, as well as the influence of curing conditions on the strength development of this material.

1 INTRODUCTION

Cement industry is one of the most pollutant industrial sectors worldwide, ranking as the third largest carbon emitting industry in the EU (Rehan, 2005, Szábó, 2006). It is estimated that each tonne of cement produces approximately one tonne of CO_2, mainly from the burning of fossil fuels and from the de-carbonation of limestone (Rehan, 2005) Due to the Kyoto protocol and growing environmental awareness, various measures concerning reduction in CO_2 emission are under study, ranging form process improvement, use of different raw-materials and alternative fuels (Gäbel, 2005, Rehan, 2005, Szábó, 2006). A valid possibility is the use of pozzolanic materials (Gartner, 2004) either with the traditional cement binder or with other binders such as air lime or hydraulic lime, which are themselves less pollutant than cement. These materials have been used in structural concrete since Roman times, attaining great durability, evident in buildings such as the Pantheon in Rome.

Pozzolanic materials are characterized by the ability to react with lime (calcium hydroxide) in the presence of water, forming calcium silicate hydrates. These materials, of natural or artificial origin, must contain a high percentage of amorphous silica and a high specific surface in order to generate a pozolanic reaction. Currently, the re-use of waste materials with pozolanic properties is a growing reality as cementitious materials are widely applied and provide a suitable application possibility with evident advantages (mitigation of AAR, increase in mechanical strength, among others). Amongst these, products deriving from clay calcination, such as metakaolin, are starting to e applied in Portugal. The residue of expanded clay production used in this study is a similar product, resulting from clay calcinations at temperatures surrounding 1200ºC. Collected as a fine powder, or grinded, this material is a strong possibility for use in concrete ad mortars.

Portland cement is the usual binder for concretes, due to its deeply studied performance and achieved resistance. However, high resistance concrete is unnecessary for some applications and in this field other, less pollutant binders, such as hydraulic lime may be used. Hydraulic lime production decreases CO_2 emissions in 82% compared with cement production (Portland Cement Association). In order to increase mechanical resistance of hydraulic lime concretes, pozzolanic additives may be used.

2 CHARACTERIZATION OF EXPANDED CLAY RESIDUE

Obtained during the process of expanded clay production, this residue is a fine material with the same composition as expanded clay. It was characterized by X-Ray Diffraction (XRD) in terms of mineral composition and by X-Ray Fluorescence (XRF) for the determination of chemical composition.

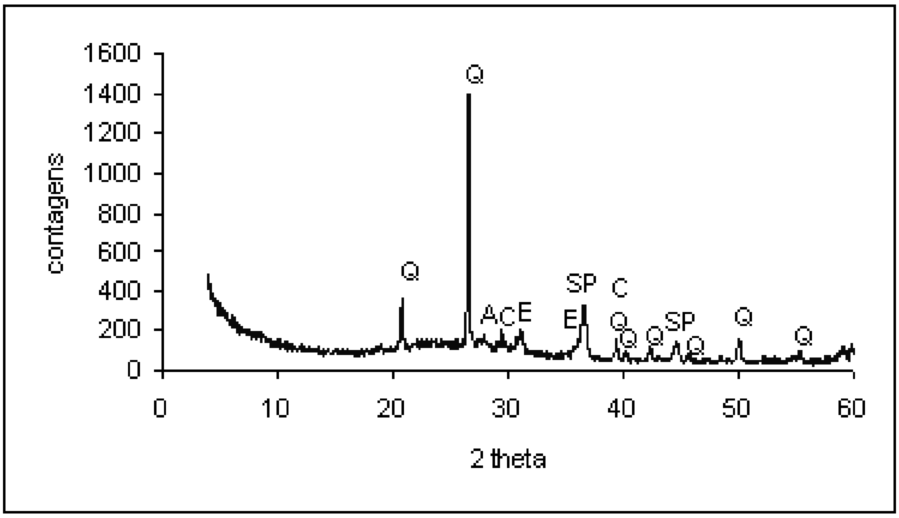

Figure 1 – XRD of expanded clay residue.

Expanded clay residue, ECR, is mainly composed of quartz (Q), spinel (SP), calcite (C) and feldspars (A, E). It has a small but evident band ranging from 20º to 30º, indicating the presence of amorphous material (Figure 1). Silicates and aluminates are predominant in terms of chemical composition (Table 1) that also indicates the presence of iron, calcium and basic elements (sodium and potassium).

Table 1 - Chemical composition of expanded clay residue.

Oxides	CaO	SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	TiO_2	P_2O_5	MnO	L.O.I.
Percentage in weight	3.92	56.52	19.50	8.05	4.58	3.97	0.33	0.95	0.18	0.14	0.70

3 METHODOLOGY

Aggregates used in this study were natural sand and calcareous coarse aggregate. Hydraulic lime was NHL 5.

Table 2. Mixture composition.

Name	Constituents [kg/m^3]					
	Agg. 10-25	Agg. 5-10	Sand	NHL 5	ECR	Water
M0	381.5	945.6	67.3	550	-	247.5
M2		945.6	67.3	440	110	247.5
M3		945.6	67.3	385	165	247.5

The developed experimental program was designed to assess the effect of the addition of expanded clay residue on the mechanical strength of hydraulic lime concrete. Hydraulic lime was replaced by 20 and 30 % of expanded clay residue, by weight. The results were compared with a reference mixture containing only hydraulic lime. Table 2 summarises the three different compositions. Water/cement ratio was 0.45. Different curing conditions were used where the relative humidity, RH, of the environment was changed. Concrete specimens were cured immersed in water, at 90 % RH and at 60 % RH. The temperature was kept constant at 20 ºC.

Compressive tests on 15 cm cubes were performed at 7, 28 and 90 days according NP EN 12390-3:2003 standard. Additionally, workability of fresh concrete was measured using the slump test (NP EN 12350-2:2002).

4 RESULTS AND DISCUSSION

Slump results are all in the range 0.5 to 1.5 cm that indicates a rather small workability of concrete. Since the aim of this study was the investigation of the effect of expanded clay residue and of curing conditions, this lack of workability wasn't considered a very important issue at this stage. Nevertheless, this is an important aspect that must be accounted for in the subsequent development of the study that can probably be solved by addition of a plasticizer.

The effect of the curing conditions on the compressive strength of limecrete can be observed in Figures 2 to 3. It is apparent from the figures that reference limecrete, mixture M0, has higher strength if cured at normal conditions (20 ºC and 60 % RH) than in a saturated environment.

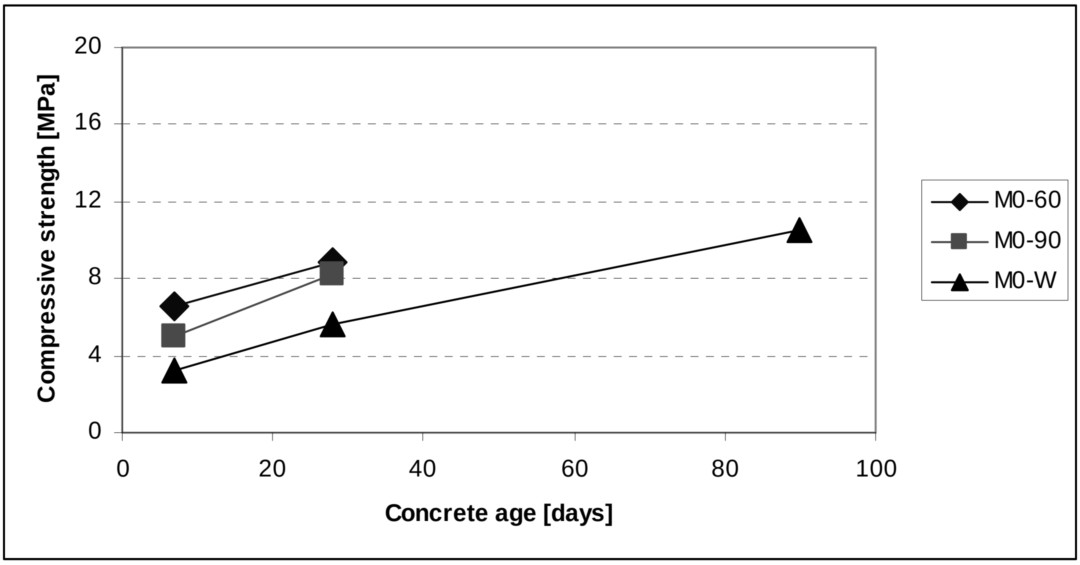

Figure 2. Compressive strength in different curing conditions for mixture M0.

The presence of expanded clay residue (Figures 3 and 4) reverses the situation. For mixture M3 the effect of curing conditions is quite apparent, especially between 28 and 90 days, where a 60 % increase in strength can be observed if specimens are cured in a saturated environment. The results observed for mixture M2 show transition behaviour between mixtures M0 and M3, as can be easily seen in Figure 5. Thus, it seems clear that when expanded clay residue is used, curing in saturated conditions is better.

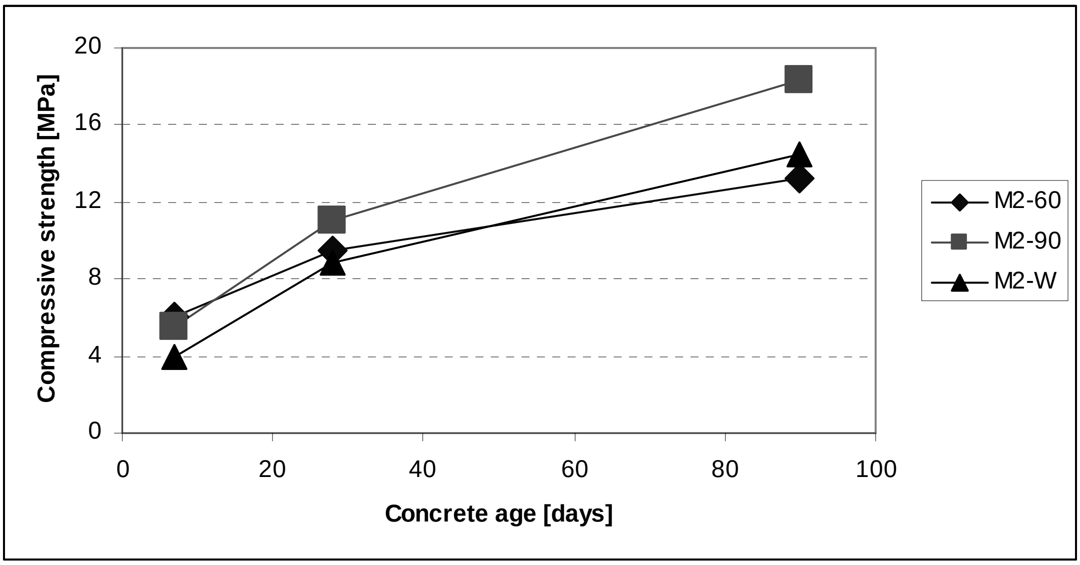

Figure 4. Compressive strength at different curing conditions for mixture M3.

The addition of expanded clay residue only has a beneficial effect on strength at 90 days and in saturated curing conditions or under water.

Figure 5 shows results of mortars cured in different curing conditions at age 28 days. Although this is too early to asses the influence of the addition of pozzolans, the behaviour of hydraulic lime concrete with expanded clay residue is slightly improved in saturated conditions or under water.

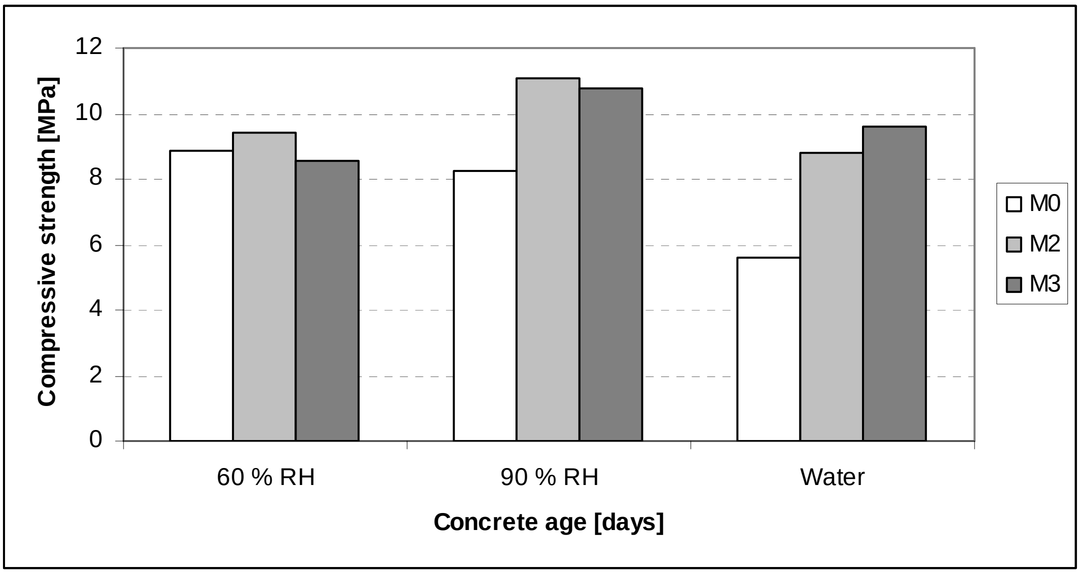

Figure 5. Compressive strength at 28 days.

These results show that the influence of curing conditions at early ages is small but becomes evident at age 90 days. Additionally, concretes with expanded clay residue perform better in saturated curing conditions or under water. This may be explained by water demand of the pozzolanic reaction, which is slower than hydraulic reaction but will only take place in the presence of available water. This slower reaction will only produce visible results at later ages, accounting for the differences between results of concretes stored in saturated conditions or under water at age 90 days.

5 CONCLUSIONS

Expanded clay residue is a suitable material for application in concrete with hydraulic lime binder as a pozzolanic addition. A substitution of hydraulic lime by 20% and 30% expanded clay residue produced increased compressive strength at adequate curing conditions, especially in the latter case.

As results indicate, curing conditions produce significant changes in mechanical strength, but not at early ages, due to the development of chemical reactions in time. Daily variations of environmental conditions, reaching peaks of over 90% relative humidity, favour pozzolanic reaction and the addition of pozzolans to hydraulic lime.

The use of these materials contributes towards the production of sustainable concrete. However, these are preliminary studies and further studies need to be conducted towards the improvement of workability (using less water and introducing plasticizer) and characterisation of hydraulic lime with pozzolan behaviour at latter ages, aiming towards definition of usage possibilities in construction.

REFERENCES

Gäbel, K. & Tillman, A. 2005. Simulating operational alternatives for future cement production. Journal of Cleaner Production 13: 1246-1257.

Gartner, E. 2004. Industrially interesting approaches to “low-CO2” cements. Cement and Concrete Research 34: 1489-1498.

Lázló, S., Hidalgo, I., Ciscar, J.C. & Soria, A. 2006. CO2 emission trading within the European Union and Annex B countries: the cement industry case. Energy Policy 34: 72-87.

Portland Cement Association. Cement Industry Fact Sheet from EBN, Vol. 2, n.2.

Rehan, R. & Nehdi, M. 2005. Carbon Dioxide emissions and climate change: policy implications for the cement industry. Environmental Scienece and Policy 8 (2): 105-114.

Structural Aluminium Alloys and Sustainability in Building Applications

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ABSTRACT: In the present paper, the influence of structural aluminium alloys in the sustainable character of structures, namely ecological and economical performance throughout their expected lifetime is presented. Aluminium alloys represent a series of relatively new structural materials that incorporate special characteristics in terms of sustainability. In particular, durability, recyclability, low maintenance costs and high reflectivity are some features among others that prove the environmental-friendly character of them. There is a large number of aluminium alloys which differ to each other due to chemical composition and the process they have been subjected to, thus each aluminium alloy exhibits a different behaviour. The scope of the present research effort is to present all the special characteristics of the most commonly used aluminium alloys and their effect on building applications regarding energy efficiency and conservation. The influence of material special features on the phases of Life-Cycle Analysis (LCA) and their role in sustainability evaluation has been thoroughly discussed, while at the final part of the paper, special mention with respect to intelligent aluminium buildings and their interaction with the exterior environment has been made.

1 INTRODUCTION

It is undoubtful the fact that the uncontrolled human activities along with the industrial operations carried out through years have severely damaged the environment. The greenhouse effect, the depletion of the ozone layer and the climate change are some of the phenomena that characterize the nowadays situation. As the consequences of environmental burdens have day by day negative influence in a more directive way to our daily life, the need for taking immediate measures for the protection of the environment is deeply felt by more and more people everyday. A global ecological concern is being developed and the majority of industries worldwide are starting to adopt friendlier approaches to the environment.

In this framework, all factors in the building industry have started investigating for techniques in order to deal with the environmental unfriendly operation of buildings. When considering the full lifetime of a structure, the building sector is the biggest consumer of raw materials and energy, while the role of environmental parameters regarding the design and construction of building applications is becoming more significant. In the construction field, the need to reduce the consumption of fossil sources of energy, to deal with the problem of material flow and waste production and its treatment is imperative. In the last years, the green building perception has started to become a nowadays trend, whereas the necessity to adopt an approach in assessing the impact of building activities on the environment, economy and society is recognized by all factors in construction business.

The concept of "sustainable construction" has been developed which involves minimizing building costs, materials and waste, minimizing energy use and improving energy efficiency of the structure. Sustainability also includes low operating and maintenance costs, along with creating the conditions for healthy, safe and comfortable living. Furthermore, it includes also the choice of recyclable construction materials and products, as saving energy is a major objective and the removal or not of materials at the end of their life cycle is dependent on this choice. In addition, sustainable design means considering the whole lifetime of a structure, investigating ways of reducing the environmental impacts of building activities, importing the assessment of life-cycle costs of buildings in the primary process. In this framework techniques and methods of minimizing the release of emission and the consumption of resources in the construction of building products in transport, installation and maintenance during their service life, are also included in sustainable design. Generally, sustainable building is the building where the principles of sustainable development in the construction industry are applicated. These are to optimize structures depending on their requirement at 3 levels simultaneously, namely ecological, economic and socio-cultural (Maydl 2006).

The scope of the present research effort is to focus on environmental perception and to investigate the relationship of sustainability and aluminium alloys material. Aluminium alloys are new constructional materials comparable to steel or concrete and can contribute to sustainability of structures. Their physical and mechanical properties can provide buildings a green performance in terms of ecology and economy besides functionality and structural stability. This paper aims at presenting some of the most commonly used alloys and all their special features that contribute to sustainability. Life cycle analysis procedure is described and special mention has been made regarding intelligent facades and future expectations.

2 ALUMINIUM ALLOYS AND BUILDING APPLICATIONS

In civil engineering works, aluminium is concerned usually as a metal whose basic ingredient is either aluminium or aluminium alloys. Pure aluminium is a metal with a strength varied from 90 N/mm^2 to 140 N/mm^2, thus its use in construction is reluctant. When it is added with other metals such as Mg, or Si though, aluminium alloys are formed whose strength is high and in some cases it can reach to 500 N/mm^2 (Kissel & Ferry 2002). Aluminium alloys are classified in various categories regarding their chemical composition and their further process they are subjected to, where every alloy is characterized by unique properties and exhibits different structural behaviour. Aluminium alloys are divided into two categories, namely wrought alloys which are worked to shape and cast alloys, which are poured in a molten state into a mold that determines their shape. While strength and other properties for both products are dependent on their ingredients or the selective addition of alloying elements, further variations on these properties can be achieved by tempering, a process that refers to the alteration of the mechanical properties of a metal by means of either mechanical or thermal treatment. Temper can be produced in wrought products by the strain-hardening that results from cold working. Thermal treatments may be used to obtain temper in cast products, as well as in those wrought products identified as heat-treatable. Conversely, the wrought alloys that can only be strengthened by cold work are designated non-heat-treatable. Regarding wrought aluminium alloys, the basic types that are used in industry and construction are summarized in Table 1.

Table 1. Basic categories of aluminium wrought alloys.

Series number	Primary alloying element
1xxx	None- Pure Aluminium
2xxx	Copper
3xxx	Manganese
4xxx	Silicon
5xxx	Magnesium
6xxx	Magnesium and Silicon
7xxx	Zinc and Magnesium

Wrought aluminium alloys are tempered by heat treating or strain hardening to further increase beyond the strengthening effect of adding alloying elements. They are divided into two groups based on whether or not their strengths can be increased by heat treating. The classification depends on the alloying elements and generally, the 1xxx, 3xxx, 4xxx, 5xxx series wrought alloys are not heat treatable and can only be strengthened by cold working, while the 2xxx, 6xxx and 7xxx wrought series are.

Aluminium alloys represent a wide family of constructional materials, whose mechanical properties make them extremely popular in civil engineering works and cover an extended range of application fields. In addition, their physical properties, such as lightness give advantages as erection phases can be simplified, as the loads transmitted to foundations can be reduced and as the physical labour can be reduced. Another characteristic of aluminium alloys is their corrosion resistance which results in reducing the maintenance costs and adopting a good performance in highly corrosive environments (Efthymiou 2005). It is noteworthy that the functionality of aluminium alloys regarding geometrical shapes can make them really competitive as the geometrical properties can be improved through the design of sections, as stiffened shapes can be obtained without using built up systems and as simplifying connecting systems among different structural members, thus improving joint details (Baniotopoulos 2003).

Aluminium applications can be both structural and non structural. Regarding structural applications, aluminium alloys are usually used in large span roof systems, where live loads are small compared to dead loads. In addition they are used in structures located in inaccessible places far from the fabrication shop, thus they can provide transport economy and ease of erection. In structures like swimming pool roofs, harbour elements, river bridges, which are characterized be humid environments, the aluminium alloys is preferable (Mazzolani 1995).

In the building sector popularity of aluminium alloys in load carrying structures as well as in secondary or decorative elements has increased significantly over the past 50 years. Currently, a total of 26% of all aluminium products is used in building applications. Where with 51% they represent the biggest customer of the extrusion market and cover 11% of the rolled products market. All kinds of aluminium products are used in new home construction and in rehabilitation and renovation of existing structures. The range of building applications of aluminium is extensive: it is commonly used in the building envelope for facades, glazed and roofing systems, curtain walling, window frames and doors. It is also applied for railings, balconies, staircases, heating/ air conditioning and solar elements (Fig. 1) (European Aluminium Association 2004).

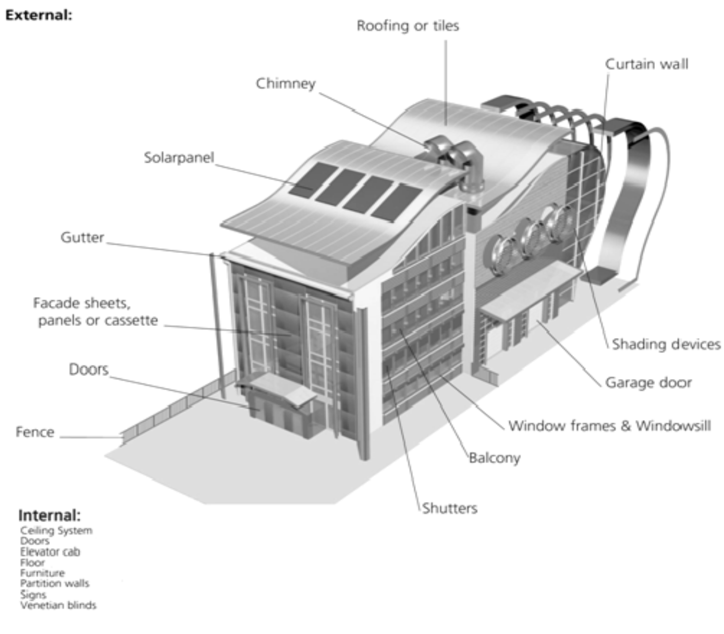

Figure 1. Aluminium in building applications

Regarding aluminium alloys series and their usage in building applications, non heat treatable alloys of 3xxx series as AW 3103, which are characterized by rising strength and big corrosion resistance are mostly used in cladding systems, in façade engineering. Alloys of series 5xxx are very corrosion resistant, exhibit good weldability and alloys like AW 5083, AW 5454 are used in chemical plants and road tankers. The most commonly used series is that of 6xxx series, where alloys like AW 6063, AW 6061, AW 6082 are used in architectural extrusion window frames and roof trusses (European Aluminium Association 1999).

3 SUSTAINABLE CHARACTER OF ALUMINIUM ALLOYS

3.1 *Sustainable features of aluminium alloys*

From the sustainable point of view, aluminium alloy structures provide great credibility when a long term approach is being adopted. Despite the initial high cost and the great amounts of energy consumption during production, the special features of alloyed aluminium enable sustainable performance when the consideration refers to the whole service lifetime of the structure (Radlbeck et al. 2004).

To begin with, building aluminium material has a very long life cycle, ranging from 30 to 50 years and due to durability, the maintenance costs are very low over the lifetime of the structure. In addition, the majority of alloys used in construction are weather-proof and corrosion resistant, thus a long serviceable lifetime is assured. Another important characteristic of the material is its high reflectivity, which can be exploited in several building techniques and systems. An example of this is when aluminium solar collectors are installed to lower energy consumption regarding heating in winter and artificial lighting while there is the case of aluminium shading devices reducing the need for air-conditioning in the summer. Furthermore, aluminium alloys exhibit excellent recyclability. Used aluminium products and scrap can be recycled and at the same time the environmental impact related to recycle processes is reduced. As almost all aluminium material used in construction can be recycled, the considerable energy invested in the production of primary aluminium can be reinvested into other aluminium products. Scrap may not necessarily be recycled back into its original product or even reused in the country in which it was first manufactured, but the original energy investment will not be lost.

Concerning structural applications and aluminium alloys, their strength, weight and versatility make them ideal building and cladding materials. Since they are corrosion resistant, they are mostly used in maintenance-free applications such as siding, windows, skylights, doors, screens, gutters, down spouts, hardware, canopies and shingles, etc. Regarding aluminium siding, systems are also available with insulation and reflective foil backing, so walls can be made weatherproof and energy-efficient. A layer of insulated aluminium siding is four times more effective than uninsulated wood siding, four inches of brick or ten inches of stone masonry.

In addition, the relatively low melting point (660°C) of aluminium alloys means they will "vent" early during a severe fire, releasing heat and thereby saving lives and property. Regarding recycling, aluminium not only has important economic implications but also contributes to environmental production, whereas depositing or incineration does not have harmful side-effects even if inadvertently dispersed in the environment.

3.2 *Embodied energy*

The embodied energy of a material is a measure that compares the amount of energy required to produce an equal mass of different building materials. The measure is often misinterpreted as a measure of environmental impact or sustainability despite the fact that embodied energy fails to take into account the entire life cycle of a building.

Primary aluminium production is energy intensive and because of this has been criticised on the assumption that the volume of embodied energy in some way equates with the volume of greenhouse gas emissions as a result of the electricity generation process and the actual smelting process. In case of aluminium alloys this is not true. The embodied energy approach takes no account of differences between energy sources (International Aluminium Institute 2003). A focus on the energy embodied in a material can often lead to a choice of material that may not be the best one from a whole of life perspective. The optimum choice of a material in any application involves tradeoffs and a compromise between factors like cost, availability, ease of construction, surface finish and maintenance requirements. The embodied energy of materials, represents only a small percentage of the total life cycle energy requirements of a building, nor does it consider other environmental burdens, for example emissions and resource depletion.

The use of embodied energy is therefore a rather misleading approach and could, for example, lead to a building that is at the same time energy intensive during its use phase and energy intensive to maintain. This could also result in a considerable environmental burden during the demolition and disposal phases.

3.3 *Life Cycle Analysis and Aluminium*

When choosing a material for any application it is important to look at the whole of the product's life cycle. Life cycle analysis in fact goes far beyond the production processes alone. It also covers the impacts and benefits of the material throughout the lifespan of the different aluminium products, including its re-use and recycling. The typical building will have four major parts to its life cycle; construction, use (mainly heating, lighting & air conditioning), maintenance and demolition/disposal. In this case, the "use" phase of the building's life takes 63% of the building's energy requirements while the repair and maintenance take 19%. The materials and construction account for only 10% of the building's energy requirements. Choosing the right material for the right application is therefore critical in reducing all the energy requirements over the life cycle of the building.

The life cycle of aluminium alloys is divided into several stages. In the first phase which refers to design and calculation, various alloys with different characteristics and strength values are considered. According to the type of alloy, high strength values, even within the range of steel, are available. The low material density values of aluminum can reduce the total weight of structures significantly, with savings up to 50% of comparable steel sections. Static design and quality control are covered in various standards, currently being further developed and harmonized. The second phase includes the production, transport and assembly. Production of 1ton of aluminium requires 4 tons of bauxite. The subsequent chemical and electrolytic processes consume a rather high amount of energy. For the production of one ton primary aluminium currently an average of 15.5 MWh sufficient for the production of 5 tons of steel are required. Depending on product, cross section form and respective energy price the initial cost is rather high, but may vary widely. Due to its light weight and its high grade of formability aluminium cuts costs, energy and time in transport and erection too. The next stage is the use- service phase. The natural corrosion resistance provides a high level of durability, together with minimum inspection and maintenance requirements. This leads to significant cost and energy savings, especially in comparison to other materials requiring regular painting. Aluminium in the building envelope requires well-planned thermal insulation because of its high heat conductivity value (λ_{RAlu}=200, λ_{RAlloy}=160) compared to other building materials (λ_{RGlass}=0.80, λ_{RSteel}=60). The dismantling, transport and recycling procedures are the final phase in the life cycle, as the disposal of a relevant matter, being non-hazardous and of high scrap value.

Aluminium structures are easy to dismantle and transport, while the recycling process is carried out with only 5% of the input energy for primary aluminium and with no loss in quality. Currently, a recycling rate of 85% is achieved in the building industry. In total 6% of recycled aluminium is reused in building structures. The final phase of a building's life needs to also be considered when making material choices. Ideally the material will be recycled in an economically and environmentally sustainable way. Usually the least desirable option is landfill, whereas a large amount of waste building materials goes to landfill sites at a cost to both the economy and the environment; others are recycled at a cost to the community. In contrast, aluminium is recycled in a way that pays for itself and is sustainable. Aluminium has a low melting temperature and is therefore able to be recycled with comparatively little energy. The energy required to produce secondary ingot from scrap is only about 5% of that required to produce primary aluminium. About 30% of the world's annual aluminium usage is supplied from processing post-consumer scrap. Indicatively, life cycle analysis of an aluminium window is depicted in Figure 2 (Asif et al. 2002).

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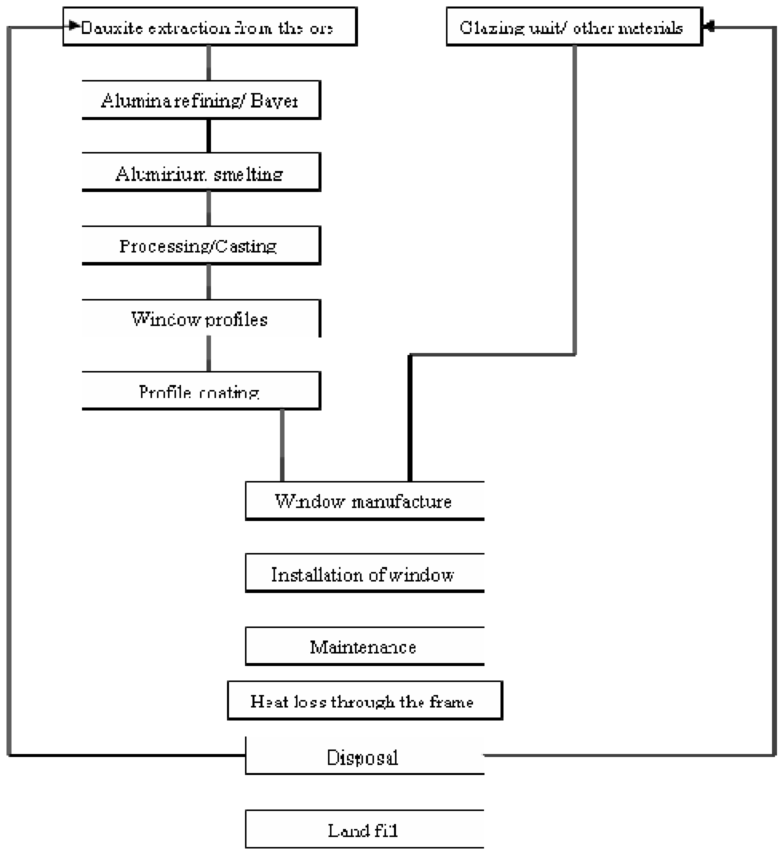

Figure 2. LCA- Building product: Aluminium window

4 CONCLUSION AND PROSPECTIVES

The construction industry is faced with a number of environmental issues ranging from its direct impact on climate change to its choice of materials and its methods of waste disposal. The entire life cycle of a building must be considered when assessing these issues. At the same time environmental considerations need to be balanced against the realities of design, function and economy. When choosing the optimum material for each building an approach which takes account of the full lifetime of the material should be adopted, covering construction, use, maintenance and disposal phases. When planning an environmentally sustainable and cost effective building, factors like minimal energy minimal maintenance, suitability for local climate and minimal waste should be considered. Furthermore low material toxicity and high material recyclability must be also design aims of a green perception.

Aluminium alloys can make a valuable contribution towards achieving these environmentally friendly goals, when used appropriately. Increasing demand for adequate and sustainable performance with high quality materials in structures offers an opportunity for aluminium alloys since they possess properties such as formability, functionality, flexibility, light weight, excellent recyclability and corrosion resistance. Despite the fact that aluminium alloys are characterized by high energy consumption during their production and initial costs, they perform in a sustainable way with the consideration of the building in the full service lifetime.

Nowadays, new building systems and innovative design concepts regarding aluminium alloys cooperating with building elements are adopted in order to provide more sustainable solutions and to meet future ecological demands. In particular intelligent facades incorporating aluminium systems that can decrease energy consumption in buildings up to 50% have just started to appear in european construction era. They are characterized by constructive interaction with the exterior, markedly reducing heating, cooling, ventilation and lighting energy demands. New technologies mean solar power captors can be inserted in aluminium frames, thus saving considerable amounts of energy and protecting the environment. Numerous techniques are being adopted and processes including photovoltaics, optimised ventilation mechanisms and appropriate light and shade management are applicated in order to ensure long term sustainability and at the same time static stability and fitness. By means of these innovative systems, where aluminium is the basic structural element the environmental performance of constructions can be improved and thus providing more sustainable solutions.

5 REFERENCES

Asif, M., Davidson, A. & Muneer, T. 2002. *Life cycle of window materials- A comparative assessment; Proc. of CIBSE National Technical Conference. London: CIBSE*

Baniotopoulos, C. C. 2003. *Structural Metal Connections in the Framework of Eurocodes 3&9*. Thessaloniki: Ziti Publications

Efthymiou, E. 2005. *Development of yield lines in aluminium bolted joints under tension. A numerical and an experimental approach*. Dissertation. Aristotle University of Thessaloniki.

European Aluminium Association (EAA). 2004. *Building*, Brussels: European Aluminium Association (EAA). www.eaa.net

European Aluminium Association (EAA). 1999. *TALAT "Training in Aluminium Application Technologies"*, Brussells: European Aluminium Association (EAA).

International Aluminium Institute. 2003. *Life cycle assessment of aluminium: Inventory data for the worldwide primary aluminium industry*. London: International Aluminium Institute www.world-aluminium.org

Kissel, J. R. & Ferry, R. L. 2002, *Aluminium Structures: A guide to their Specifications and Design (2nd edition)*. New York: John Wiley & Sons Inc.

Maydl, P. 2006. Structural Sustainability-the Fourth Dimension?, *Structural Engineering International*, 3:268-269.

Mazzolani, F.M. 1995. *Aluminium alloy structures.* London: E& FN Spon.

Radlbeck, C., Dienes, E. & Kosteas, D. 2004. Sustainability of Aluminium in Buildings, *Structural Engineering International*, 3:221-224.

Eco-efficiency and the sustainability of traditional Turkish houses

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ABSTRACT: The Turkish House can be defined as the types of houses which Turks have lived in throughout history. The timber frame construction is compatible with the forest cover of Anatolia and the Trace region and is also preferable because these regions are within the seismic zones. Furthermore, this method enabled quick construction and therefore suited the needs of an ever-expanding society, continuously on the move. For the same reason the details of wood construction are very simple; simple joints and nailed bindings have been preferred to complicate joint details. This construction method also facilitated the reconstruction, within a short time when whole quarters were destroyed instantaneously by fire. The basic-system of construction is the timber frame with infilling material or the lathe and plaster. In this paper the traditional Turkish Houses will be examined in the frame of sustainability of the timber frame construction system. The sustainability criteria are summarized below and will be discussed with several cases.

1. GENERAL INSTRUCTIONS

1.1 Vernacular Settlements and the Turkish House

Since the beginning of tribal acts of the human beings, housing has been one of the main needs of the mankind. Within this need, many settlements were formed and most of them grew, becoming the cities of today. This mature brought different variations of settlements depending on the cultural, economical, physical features of the environments and communities, which they were built in. A fast examination on these settlements may form an idea of complete difference at every comparable element. But a closer look could point out to some similarities of the formation of the settlements. These can be the materials, construction techniques, and formation of the house plans and body according to the weather conditions and sunlight or the topographic features of the environment.

The Turkish House we know today has begun to be formed during the settlement of the nomadic Turks from the Middle East to Anatolia. This type of housing has spread through the Southern Anatolia to the Balkans forming a large area of social and cultural typology. The principles of construction for the houses mostly are the same but the cultural details completely vary.

Accepting the Islamic religious life and settling in Anatolia as a homeland, and changes in the cultural and social characteristics joining with the aerial properties of Anatolia, like climate, topography, materials etc., started the progress of a new settlement style and house typology, Turkish house.

There is very little information on the process of the development from the tent to the Turkish house. The migration according to the seasons, as an action shows itself within the Turkish house as a movement to different floors of the house or as moving to a nearby summer or winter house. The rooms in a house are considered as a family's room, like tents. Whole life of a family is lived in this room. Other room's shelter the other families related to the main parents of the house like aunts, uncles, sons, etc.[1] The rooms open to a main hall named as "Sofa" bringing forth the strength and the privacy of the relations and bonds within a family. This is the main fact that is preserved in a Turkish house, Turks' being a "Family Based" community. Rooms are the private areas where the sofa is used as the family room of the house.

Figure: Room and the Sofa of Traditional Turkish Houses

The vernacular settlements have developed with a similar process just like the Turkish house. The main fact about the settlements is to acquire a source of any kind in order for the community to survive and defray their needs. The settlements begun when this point is reached. Just like the settlements, the decision for the area needed for a house is decided by the needs of the family and an area is bordered for construction of the house. At this point the relations with the street, or in other words "the community" is shaped and formed. High garden walls with an organic formation of the streets and roads according to the topographic criteria is the mostly seen part of a vernacular settlement. And finally the houses are built in these areas. The ground level is formed by the organic development of the streets where the upper levels are built with wooden frame structures forming a 3rd dimensional accent.[2]

Figure 2: Settlement Characteristics

For example because the settlement in Tire has developed at the foot of a mountain, the houses face towards the main panorama and as a result of this the streets are desolate. But in Kula the settlement has developed at a plain therefore the houses has no other social inclination than the streets and therefore the houses face to the streets with closed balconies named as "Cykma" or to their own garden areas with open spaces as "Sofa".

1.2 The Eco-efficiency of the House and Settlement Behavior

The only effective factor which human being cannot change and have to adapt his constructions and settlements to is climate. The sun, moisture, cold, heat or the winds are the main aspects of climate. The vernacular settlements are generally formed as concentric settlements in desert conditions and climates, or separate and dependently formations according to the wind and the sun in moist areas. For example in Antalya the vernacular houses are built facing the offshore breezes where the drying effect of the breeze on moisture is used. But in contrast with this act, in Diyarbakir, the settlement is concentric in order to form a protection from the sun and drying desert climate. From these examples it can be observed that the climate in Anatolia differs in many areas. This affects the width of the streets directly in vernacular settlements. The houses in desert areas are more deserted from the streets than the houses in moist areas.

"Sofa" – the open family areas of the Turkish house is one of the main element of the vernacular settlement facades. The sofa is shaped due to the weather conditions. The Turkish house plan types were first classified by S.H.Eldem.[3] The most significant of these, with proper order of development are: Outer sofa, inner sofa and central sofa types. Location of the sofa indicates the main criteria of the settlement. It is mostly located at the most important place of the house. In desert climates "sofa" is always placed in the middle of the house or in some examples it does not exist. In Tire "sofa" is mostly placed according to the visual criteria but being on the foot of a hill the "sofa's direction can be dedicated considering the climate effects like the sun direction and local permanent winds.

Sun is one of the main criteria in the formation of the vernacular settlements' facade. The walls facing to North are mostly solid and as thick as possible. The walls facing the south facade are mostly designed for the location and climate criteria's in order to get a better use of the sun. The eaves of the vernacular settlements' facades are also formed according to sun. The length of the eaves changes the character of the settlements directly. For example in Kula the eaves are long and because of the concentric formation of the settlement and the narrow streets give the façade-shadowed areas for use and a more cool air circulation within the settlement. A closer research on the eaves points out a group of values matching the sun light directions of the seasonal turns. The lengths of the eaves are directionally related with the areas' seasonal turns' sun direction angles.

Room is the second significant element of the house after Sofa. The closet-cupboard is the most important element within the room. Every room has its individual closet. The purpose of the wooden closet in the houses is to obtain the noise control between two individual rooms located side by side, and the "sofa" placed between the rooms.[4] The wooden floors are covered with carpets to obtain the heat isolation of the room. The ceiling and the ornaments of the ceiling have much more symbolic meanings than the building physics. The doors; are placed angular not to be opened directly into the rooms, just not to cause grow cold in the room.[5] The furnace is placed on the thick and solid stonewall to prevent the fire diffuse. The furnaces are placed in the rooms located near the south directions, or in the rooms, which are in the middle of the two rooms that don't have furnace equipment.

The house is located on south-north direction, to obtain more efficient daylight into the living spaces of the house. The façade has rhythmic fenestration orders, two windows are placed one below the other. The lower windows have wooden shutters. The upper window is for getting light into the room when the shutters of the lower window are closed during the cold weathers.

Effect of the topographic factors on the vernacular settlements is the areas' being in a slope or plains. Houses built in a slope area, like the foot of a hill or similar, are more independent than the houses built in plains. The criteria of a house at the foot of a hill can be the view aspects, direction of the sun or the primary wind directions where a house on plains can only consider a choice between facing the street or the garden and can only take constructive precautions for the sun or the winds of the area. Because of this the streets of a settlement at the foot of a hill like Tire, is more deserted than the streets of a settlement in a plains. But the streets of a settlement in plains are mostly the center of the social life. The streets of a hillside settlement are formed according to the topographic slopes of the area, and mostly follow the slope as parallel as possible. The connections between two or more parallel streets are made through stairs or short street connections at points where the slope drops to a comfortable value for such connections. This formation brings forth very good examples of an organic vernacular facade. Although it is expected for the plain settlements to have a more organized and functional facades, they don't. The settlements at plains are as much organic as the hillside settlements. This fact is the most important heritage of the Nomadic Turks. Never having the knowledge of an organized and well-developed settlement during the nomadic period, Turks have continued their unorganized settling manners. This resulted with today's vernacular settlements and their organic formation.[6]

3 CONCLUSION

These historical traditional settlements are preserved to nowadays since 18^{th} –19^{th} centuries. and can be an example of sustaining the eco-efficiency of the buildings. In dry and desert areas the settlement forms a concentric formation in order to protect from the sun. But in moist areas the settlement forms itself according to winds like offshore breezes. In cold areas the North walls are thick and solid, but the south walls are light and organized for the best use of the sun. The only factor, which always is tried to be controlled, is the sun. Long eaves and location of the "sofa"s are the main acts, which affect the facade of the settlement. The elements of the rooms are used both as noise, heat and the light control elements, and as elements of the houses.

References

Arû, K. A. ; 1998, Türk Kenti (Turkish City), Istanbul, Y. E. M. Publishing Co.

Eldem, S. H. ; 1984, Türk Evi (Turkish House), Istanbul, Cilt I - Iý- Iýý- Iv - V , T.A.Ç. Foundation Press.

Küçükerman, Ö.; 1996, Anadolu'daki Geleneksel Türk Evinde Mekan Organizasyonu Açýsýndan Odalar (The Rooms In Traditional Turkish Houses Of Anatolia In Case Of Spatial Organization), Istanbul, Turkey Touring And Cars Society.

Küçükerman, Ö; 1978, Kendi Mekansal Arayýsýnýn Içinde Türk Evi (Turkish House In His Own Spatial Searches), Istanbul, Turkey Touring And Cars Society.

Küçükerman, Ö.; 1995, Anadolu Mirasýnda Türk Evleri (Turkish Houses In Anatolian Heritage), Ministry Of Culture Press, Ýstanbul.

Tosun, Y.; 1969, Milli Mimarimizde Kula Evleri (Kula Houses In Cultural Heritage), Ege University , Izmir,

Sozen, M.; 2001, Türklerde Ev Kültürü (House Culture In Turks), Doðan Kitabevi, Ýstanbul.

Kuban, D.; 1995, Türk HayatlýEvi (Turkish House With "Hayat"), MýsýrlýMatbaacýlýk, Ýstanbul.

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[1] Eldem, S. H. (1984), pp. 24, Küçükerman , Ö. (1995), pp.56
[2] Küçükerman , Ö. (1995), pp.82
[3] Eldem, S. H. (1984), pp.58
[4] Kuban, D.(1995), pp.109, Küçükerman, Ö. (1996), pp.45
[5] Kuban, D.(1995), pp.121, Küçükerman, Ö. (1996), pp.38
[6] Arû, K. A. (1998), pp.76

Dynamical and thermal modelling of PDEC: using traditional chimney and new dwelling as case studies in Portugal

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ABSTRACT: The present paper is a study on the importance of thermal and dynamic simulation of Passive Downdraught Evaporative Cooling (PDEC) towers once applied to both new dwellings and refurbishments in hot-dry areas. The first step was an experiment using PDEC in a hot-dry area in Alentejo where a PDEC shower system was introduced and tested on an existing brick chimney traditionally used for summer ventilation through "chimney" effect. The next step was to validate the collected data with mathematical, thermal and Computer Fluid Dynamics (CFD) models. Finally the results helped dimensioning a PDEC tower for a private house in Castelo-Branco where this evaporative cooling system was applied in a complex volumetric room. In this case a tridimensional CFD was used to ensure a good particle routine inside the whole room thus revealing efficiency of PDEC maintaining thermal comfort conditions indoors.

1.INTRODUCTION

PDEC originates from the vernacular architecture of the middle-east and is still a common cooling device in hot-arid regions worldwide. It is a low cost and passive/low energy consumption cooling system that can improve thermal comfort and reduce CO2 emissions.

The device consists of single or multiple towers equipped with a water/vapour supply placed on the top. During the constant injection of water, droplets descend through the tower and conditions close to saturation persist throughout its length. Cool air descends the tower and exits at its base where it is delivered to the adjacent spaces. The concept is based on the relatively large amount of energy required to convert water from its liquid form to its gaseous form within a local thermal imbalance with subsequence differences in air density. This leads to the movement of air from a zone of high pressure, where air is hot and less dense (top of the tower) to a zone of lower pressure, where air is colder and denser (bottom of the tower). When the system uses only passive means, and the local thermal imbalance is caused by "free convection", it is considered passive downdraught. The movement of air inside an evaporative cool tower may occur as a result of "forced convection" produced when air is deflected by a solid object or driven by mechanical means such as an electric fan.

Since PDEC is a natural and ventilated system is important to ensure that air flow rates are vertically and horizontally balanced to ensure uniform supplies of fresh and thermally treated air. This is specially important to verify humidity stratification and local air movement to reduce risk of Legionella, condensation and microbiological growth in stagnant zones that can lead to fabric deterioration and air contamination. It is also important to prevent from high rates of exit air speed resulting from of draughts produced when water downdraught is activated.

The best way to solve the Navier-Strokes (N-S) problem of conservation of energy, movement and mass of the fluid is using a computational program, such as a CFD. Today there are few programs that allow a PDEC simulation because there is the need to recognize top-down airflows and driven forces. PDEC is often described as a "reverse chimney" because the column of cool air falls. STAR-CCM+ is a CFD program that analyses particle routine of the water and air inside the PDEC tower and adjacent room in a tridimensional way. A bidimensional CFD program can also be used although it does not reproduce the interior environment in such an accurate way.

In order to evaluate thermal and dynamical modelling of PDEC two case studies were used to analyse cooling and air routine efficiency of PDEC in two hot-arid regions of Portugal: in Moura (38º13N:07º13W), a PDEC shower system was introduced on an existing traditional chimney adjacent to a regular room with a dense occupancy. In Castelo-Branco (39º43'N:07º15'W), a PDEC system was proposed as a cooling device in a private house with complex geometry and architectural form but low internal gains.

On the first case measurements and collected data were first validated through Givoni's mathematical model and tested conditions were reproduced on a thermal and a CFD model. On the second case, a thermal model helped defining thermal performance of the building thus helping dimensioning PDEC with Givoni´s and Perlmutter et al mathematical models and defining envelope conditions. Such conditions were imputed in a CFD model to evaluate cool air movement within the room. In both cases internal conditions were reproduced according to an occupancy pattern (number of users of the space/building, heat gains from people, machinery, etc.) and physical properties of the construction (envelope, heat losses from envelope, etc.). More investigation on case study 2 will include a CFD simulation of downdraught evaporative cooling effect inside the tower**.**

Results led the author to argue about the importance of PDEC as a cooling and ventilation system in buildings that should be protected from such an extreme natural environment.

2.CASE STUDY 1 – MOURA´S TRADITIONAL CHIMNEY

The chimney object of the case study is located on the first floor of *Ateneu Mourense*, a small cultural centre in Moura. It has a cylinder shape measuring 4,8 m in height (measured from the floor of the room) and 0,9 m diameter. It is located on the first floor adjacent to a room with approximately 19 m^2 floor area and 63 m^3 of volume. The room has tree old wooden doors (two interior and one exterior), and one north-facing window with single glazing and aluminium frame. Internal and external walls are 60 cm thick, made from adobe and finished with lime. The chimney walls are in adobe 0,30 m thick. On the upper limit there are few openings. There is no lime rendering on it. The chimney is adjacent to a fireplace that has its own smoke conduct. This confirms its use as a ventilation tower producing coolness by stack effect.

2.1. *PDEC inertial shower*

2.1.1.FIELD REPORT

A single shower was placed 4,5 m high above floor plan, with coarse water. The water was provided from an existing tap on the exterior that could be easily controllable. The water flow rate was 10,5 l/min. Water did not circulate continuously in order to avoid flood problems and the shower operated for only a few minutes. Testing conditions were not ideal, especially due to the use of coarse instead of fine spray.

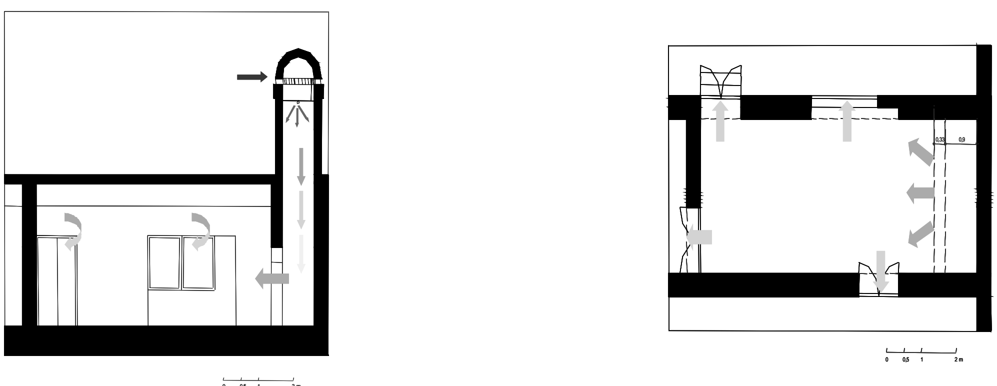


Figure 1 – Plant and Section of the chimney and adjacent room

2.2. *Measurements*

The measurements took place in the 6th of August, every hour, between 11:30 and 15:30. The room´s exterior and interior atmospheric conditions are registered on row 1 and 2 of Table 1. The drop of temperature and relative humidity registered at 12:30, is due to a breeze.

Results show that after the shower system was activated, both exit air temperature and RH were not stable on the measured periods . Temperature ranged from 22 ^{O}C to 26.6.^{O}C and RH from 62 % to 95.5 %.

To validate the experiments measured values, the outdoors climatic data and chimney physical properties were first tested on Givoni´s inertial shower mathematical model. Values obtained are very similar with the ones measured, except for those registered at 13:30. The differential is more than 4^{O}C, when the remaining is approximately 0.5^{O}C .

	Measured Parameters / time (hour)	11:30	12:30	13:30	14:30	15:30
1	Exterior conditions					
1,1	Air Flow Velocity (m/s)	0,15	0,3	0,2	0,15	0,15
1,2	Dry Bulb Temperature (ºC)	40	37,1	42,3	41,8	40,7
1,3	Relative Humidity (%)	19,7	23,4	14,2	15,5	17,2
2	Room conditions before evaporative cooling shower					
2,1	Air Flow Velocity (m/s)	0,2	0,15	0,15	0,2	0,2
2,2	Chimney Temperature (ºC)	31,2	28	31,5	32,3	33,6
2,3	Chimney Relative Humidity (%)	46,7	53,6	43,7	39,8	34,8
2,4	Room Temperature (ºC)	28,8	27,9	30,4	30,8	32,6
2,5	Room Relative Humidity (%)	48,5	50,3	42,2	39,6	31,9
3	Room conditions after evaporative cooling shower					
3,1	Air Flow Velocity (m/s)	0,5	0,6	0,6	0,6	0,5
3,2	Chimney Temperature (ºC)	26,5	25,5	22,0	26,6	23,4
3,3	Chimney Relative Humidity (%)	62	79,7	95,5	74	94,2
3,4	Room Temperature (ºC)	26,6	25,3	22,2	25,2	23,7
3,5	Room Relative Humidity (%)	56,6	75	91,7	78,6	92

Table 1-Collected data

2.3.*Modelling*

2.3.1. *Thermal Model*

TAS 8.4 was used to create a thermal model with an envelope similar to Moura´s chimney and adjacent room. It was tested according to the weather profile of the experimental day with input data from 4 people. The program does not include Moura´s weather data, so a place with similar climatic conditions was used: Phoenix, Arizona, USA because of its hot dry climate and similar latitude(33º26N:112º01E). Also, the test day was not the 6th of August but 29th of July, more similar to the climate parameters measured on the experiment day. Output data was similar to those verified on the field report.

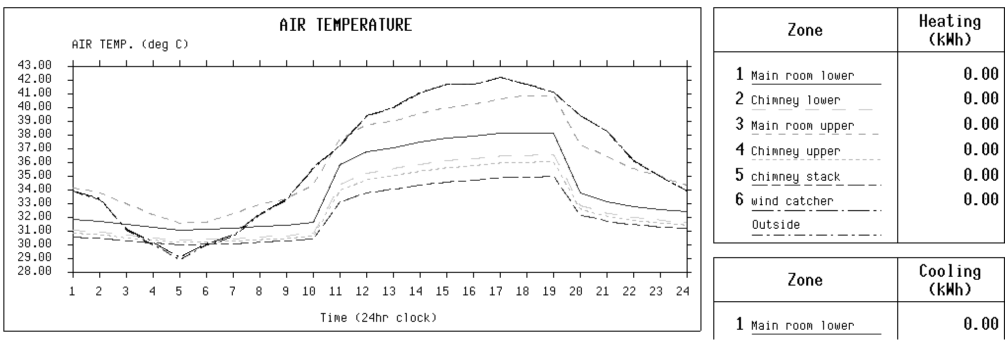


Figure 2 – Output data from TAS model

2.3.2. *CFD Model*

AMBIENS is a CFD two dimensional Cartesian grid system, in which a transversal "slice" 1m tick including exit air from chimney, was modelled. The grid represents the computational cells that will be the basis of the simulation. Building elements were not placed reproducing reality thus maximizing output information to better understand indoors thermal comfort. Therefore window and outlets (corresponding to doors gaps) are placed in the same plan, although this does not happen in any 1m slice.

Features represented are:

a) one window b) one cooling source (air inlet) c) two door gaps (air inlet and air outlet)

Please note that inlet air volume should equal outlet air volume.

Definitions of modelling included:

a) each pixel is equivalent to 0.1m height or width and 0.1m^2 area b)4 pixels for each opening, equivalent to 0.41m^2 assuming 2.5m^2 in reality

Input data for modelling included:

a) 63m^3 of room volume b) 2 ACH of infiltration, equivalent to 0.035m^3/s of Airflow Rate in the whole room, therefore 5.83 x 10 -3m^3/s in the "slice" c) air speed of 1 pixel equivalent to 0.0075m/s at 0.6m/s or 8 pixels at 0.3m/s i.e., "slice" volume divided by area of each pixel d) 0.6m/s definition of exit air speed, either 4 pixels

Temperature surface (obtained from TAS model) included:

roof - 34^o; floor - 31^{o}C; walls - 32^{o}C ; window - 40^{o}C

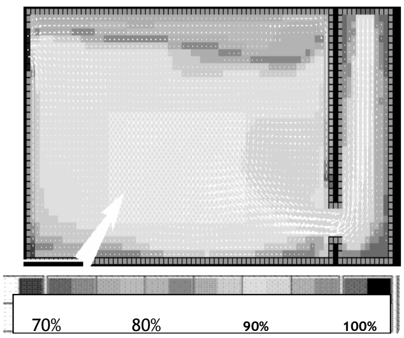


Figure 3–Relative Humidity

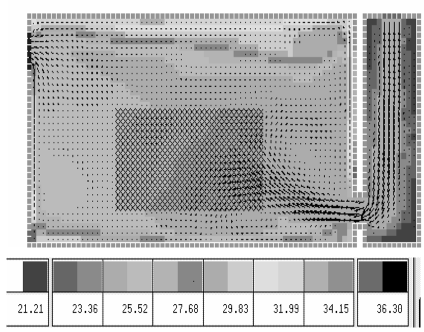


Figure 4–Air Temperature

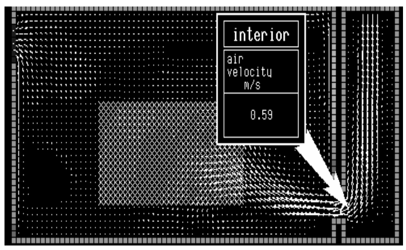


Figure 5 – Air Speed

2.3.3.*Results*

According to AMBIENS model, there is an excessive production of humidity inside the chimney (between 90% - 100%) than can lead to mould growth, Legionella and fabric corrosion inside chimney. Junctions of chimney walls and ground are especially affected and water particles that did not fully evaporate before reaching the ground can warmer situation on the bottom PDEC tower. Air beside a window has a higher RH than the rest of the room, excluding the chimney since its surface has a higher temperature. (Figure 4). Here risk of condensation is higher. However, air is distributed in a very satisfactory way within the room, and door gaps are important to help extract "old" air.

Exit air openings can play an important role defining water flow rate. Results also show that even though thermal comfort benefits from reducing on exit air speed, increase of temperature penalizes it. By reducing the water flow rate by 2.5l/min, exit air temperature will increase 1^{o}C. Regarding ventilation supply, the system is efficient since 25 people require approximately 13 ACH (assuming 8l.person.second), and the system can supply 38 ACH.

3. CASE STUDY 2 – CASTELO BRANCO PRIVATE HOUSE

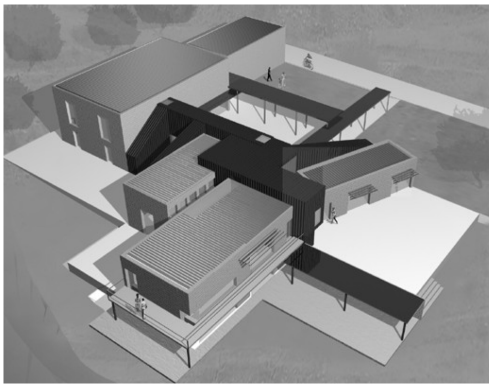


Figure 6 – Aerial view of the building

This building is located in a rural area of Castelo-Branco.It includes a private house and ateliers for sculpture. PDEC is part of an holistic environmental strategy for hot and dry periods that includes proper shading, a well insulated envelope and high thermal mass on the walls. Ground works as a temperature stabilizer therefore there is no insulation or slab on it.

The object of this study is the living room located on the south west part of the building. It has a sitting room 4.4 m heigh, a dinning room and kitchen 2.4 m heigh and a corridor 4.4 m heigh that ends on stairs and a door and links to the rest of the dwelling. It has a zenital window on it. The Floor Area is 90 m2 and the Volume is 311 m3.

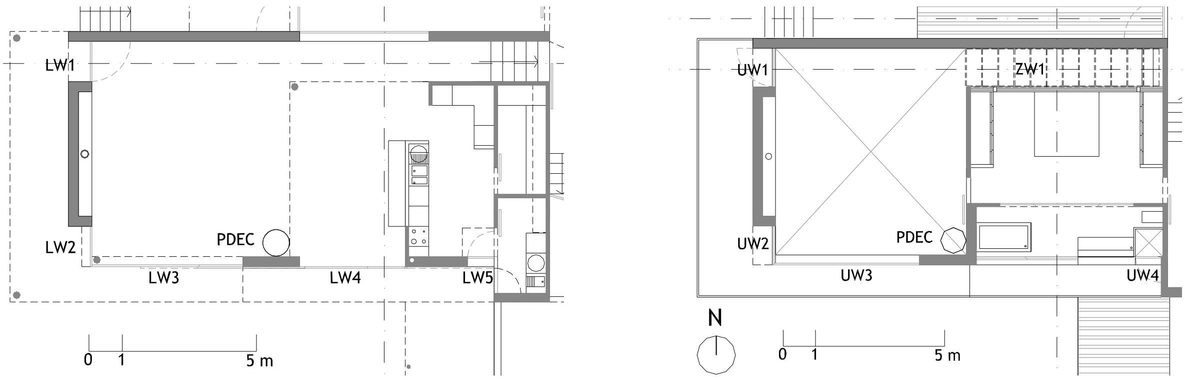


Figure 7 – Scheme of ground floor and upper floor of the living room

3.1 *Thermal Model*

First thermal performance of the building was tested on RCCTE whose results led to an estimation of energy consumption of 11.46 KWh/m2.year.

Ecotect was used to create a thermal model to obtain thermal performance of the room on an extreme hot-dry condition. Since there was no valid meteorological data for Castelo Branco it was used Cáceres (39º5N:06º5W) with similar latitude. Test day was 21st of August, an extreme hot-dry day.It was assumed 4 occupants.
Input data includes:

u - value external walls 0.43 W/m2ºC b) u-value floor 0.79 W/m2ºC c) u-value roof 0.27 W/m2ºC d) u-value windows 2.7 W/m2º e) 5 and 7 w/m2 sensible and latent heat gains

3.2. *Dimensioning PDEC tower*

Further developments of PDEC in Castelo Branco should detail design of the tower. It should include a recycling water system from domestic sources since in PDEC all types of water can be used .In a first stage and taking in account energy consumption from RCCTE and Ecotect it was assumed an aluminium frame cylindrical inertial shower PDEC tower according with parameters from Table 2. A pond needs to be placed at the bottom to collect non evaporated water particles.

Cooling Power Required	**3,95**	**kW**			
Cooling power delivered	5,37888	kW			
Minimum diameter of chimney	0,8	m	Height of shower	6,5	m
Minimum area of chimney	0,5	m2	Water flow rate	6,153846	l/min
Velocity of air flow	0,5	m/s	Exit opening	1	m2
Outdoor temp	42	degC	Air flow rate	1800	m3/hr
Desired exit temp	25,36	degC	Volume of room	311,5	m3
outdoor wetbulb temp	23	deg C	ACH	5,778491	
Indoor max RH%	70	%Rh	Water consumption		
Abs Hum ambient air temp t	10	g/Kg	Energy consumption per year	2726	kwh
Abs hum max at that temp	18	g/Kg	Money savings per year	272,6	€
Expected wet bulb depression	13,3	degC	Water Consumption	4.8*	l/min
			Water Consumption (13 h)	0,3744	m3/day
Delivered power in ambient conditions	**3,765216**	**kW**	Water Consumption (7 h)	0,2016	m3/day

Table 2 – Input parameters for dimensioning PDEC

3.2. *CFD Model*

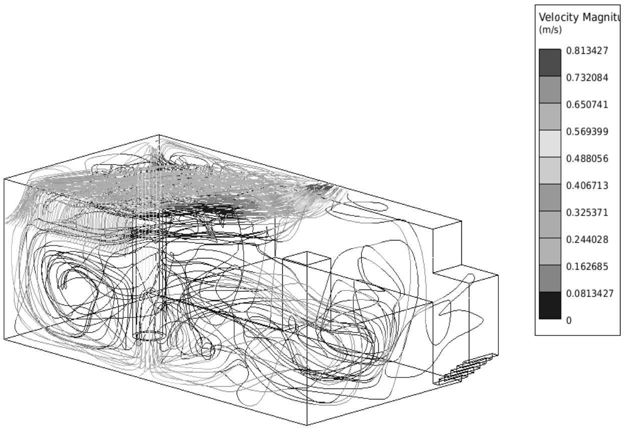
3.2.1. *Validation*

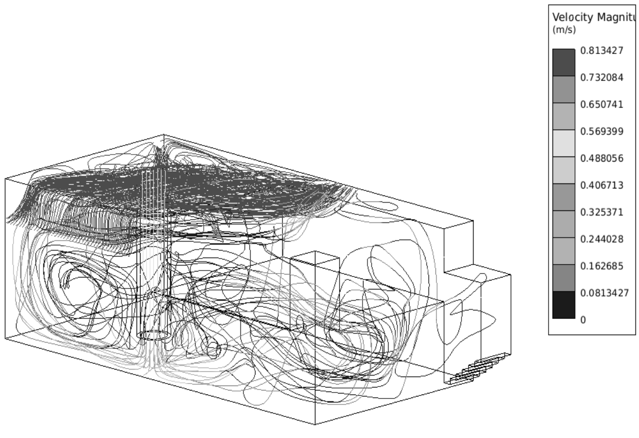
STAR-CCM+ was first subject to a verification exercise whereby a heated cavity flow was simulated. Experimental measurements were taken from Cheeswright R, King KJ, Zini S [6] who took a cavity with a 5:1 aspect ratio and a temperature difference between the longer vertical sides of 45.8 º. The top and the bottom of the cavity were assumed to no-slip adiabatic walls. The other sides are set to a symmetry condition.

3.3.2. *STAR-CCM + Model*

Radiant temperature from building envelope was necessary to build STAR-CCM+ model and this values where obtained from ECOTEC. It was assumed always the same temperature for each building element since variations according to solar orientation were negligible. Therefore glazing - 30ºC; walls- 27.5 ºC , roof 29ºC . It was assumed floor was adiabatic since it uses earth as a temperature stabilizer.

It was used 42ºC as a standard outdoor temperature and it was assumed that all the top windows would be 30% open, except UW1 and ZW1 window, that would be totally open. UW4 was disregarded. UW1 – 0.08 m3/s UW2 – 0.05 m3/s UW3 – 0.25 m3/s





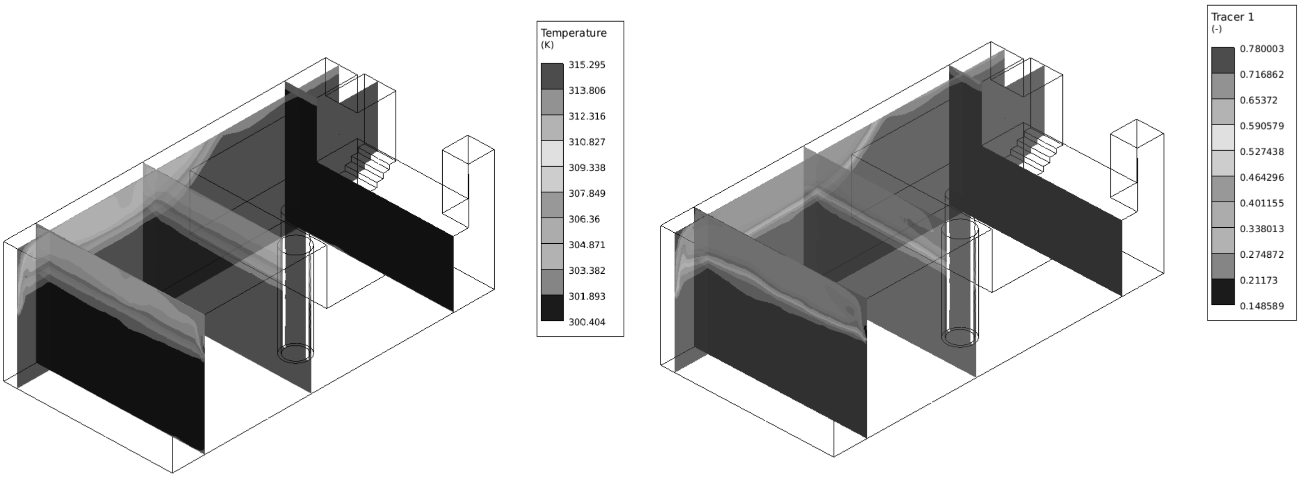


Figure 8 (clockwise) –Air Speed, Air Speed, Relative Humidity, Temperature

The model included a mesh with 123280 cells and 655088 interior faces. The working fluid was air, taken as an ideal gas. The Reynolds-averaged form of the Navier-Stokes equations was solved with the Realizable K-Epsilon turbulence model implemented in STAR-CCM+. Buoyancy was considered via the inclusion of an additional acceleration term in the momentum equations, something which is already an option in STAR-CCM+. Relative humidity was simulated as a passive scalar, to insure conservation and efficiency reasons. A second-order accurate discretization scheme was employed on all convective terms.

3.3.3. *Results*

Regarding STAR CCM+ results, a clear stratification of the indoor air happens on account of the window openings. Due to the PDEC a good mixture of the lower layer is also achieved, as can be seen in the streamline plots. Please note that the streamlines in the air coming from the windows is coloured red to better show the layering. Although this air does not mix with fresh air from PDEC it act as a "buffer" (with lower RH and higher T) helping maintaining stable and comfortable conditions (26ºC T and 70% RH) on the thermal comfort zone. This "buffer" also protects roof from excessive production of RH thus fabric deterioration due to condensation, corrosion and microbiological growth. Zenital window is important to extract "old" air. Here air velocity is high (0.8 m/s) but this phenomena occurs above thermal comfort zone. This is due to its placement on a "corner" of different walls with different heights that act as obstacles. Also air in contact with higher temperature increases its velocity. Results suggest zenital window should be placed on the end of the stairs corridor to minimize air turbulence. This kind of turbulence occurs in all the room but with air velocities much slower (0.08 m/s – 0.2 m/s) than the maximum recommend (0.5 m/s).
Results also show that exit air from PDEC has a high speed. Therefore pavement and walls surrounding tower and pond need to be impermeable and protected from water droplets that may not evaporate before reaching the ground.

4.DISCUSSION

In both studies simulation led to argue about PDEC advantages and disadvantages helping making some decisions about tower design. Simulation proved that PDEC provides appropriate rates of cooled and ventilated air at the bottom of the rooms where it can be mixed with ambient air within the thermal comfort zone. Efficiency of PDEC depends on the replacement air cycle since it deals with high rates of humidity and indoor environment can easily get saturated, i.e., air can not hold more moisture. Therefore an exhaust (like an upper window or an electric fan) should always be placed opposite to PDEC tower to extract "old" air thus renewing the air and creating a replacement cycle. Also placement of an microbial bio film on all tower surfaces in contact with water is essential , since these films can consume certain inhibitors and prevent access of inhibitors;

Nevertheless in such an extreme environment (hot-dry) PDEC seems an excellent way to natural ventilate a room. As an example, cross ventilation is not recommended since opening a window would induce warm exit air and increase interior air temperature. No ventilation at all should be avoided since internal environment becomes stagnant and no renewal of air causes thermal discomfort.

Also in PDEC natural replacement air is introduced at a high heigh where air is cleaner than in at the pedestrian level thus minimizing introduction of dust and other particles. Please note that the tower can be used as well as for night cooling through chimney or Venturi effect without PDEC activation.

However PDEC is a specific technique can help reducing the impact of global warming thus providing thermal comfort in building and occupants. In 2004 the annual temperature of Portugal increased 0.6 ºC and recent studies predict that the dry condition will affect 1/3 of the Portuguese territory.

5. ACKNOWLEDGEMENT

The author is grateful to Nelson Marques, MechEng, PhD, from blueCAPE, for his support concerning STAR CCM+ modelling.

REFERENCES

Cheeswright R, King KJ, Zini S "Experimental Data for the Validation of Computer Codes for the Prediction of Two-Dimensional Buoyant Cavity Flows" in ASME Winter Annual Meeting Anaheim, HTD-60, December 1986.

Dagmar Schröt , Wolfgang Cramer , Rik Leemans , Colin I. Prentice, Miguel B. Araújo , Nigel W. Arnell , Alberte Bondeau , Harald Bugmann , Timothy R. Carter , Carlos A. Gracia , Anne C. de la Vega-Leinert , Markus Erhard , Frank Ewert , Margaret Glendining , Joanna I. House , Susanna Kankaanpää , Richard J. T. Klein , Sandra Lavorel , Marcus Lindner , Marc J. Metzger , Jeannette Meyer , Timothy D. Mitchell , Isabelle Reginster , Mark Rounsevell , Santi Sabaté , Stephen Sitch , Ben Smith , Jo Smith , Pete Smith , Martin T. Sykes , Kirsten Thonicke , Wilfried Thuiller , Gill Tuck , Sönke Zaehle , Bärbel Zierl , "Ecosystem Service Supply and Vulnerability to Global Change in Europe" , in http://www.sciencexpress.org 27/10/2005

"Environmental Design - CIBSE GUIDE A" The Chattered Institute of Building Services Engineers, London, 1999ASHRAE STANDARD - ASHRAE Guideline12-2000, Minimizing the Risk of Legionellosis Associated with Building Water Systems, Atlanta 2000: American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc.

Fathy, Hassan "Natural Energy and Vernacular Architecture: Principles and Examples with Reference to Hot Arid Climates , UNU, 1986

Givoni, Baruch "Passive and Low Cooling of Buildings" Van Nostrand Reinhold, New York, 1994

"Passive Downdraught Evaporative Cooling (PDEC) applied to the central atrium space within the New Stock Exchange in Malta", WSP Environmental Ltd

http://www.INM.pt

Pearlmutter et all Pearlmutter D, Erell, E Etzion, Y Meier, I A, Di H "Refining the Use of Evaporation in an Experimental Down-draft Cool Tower",Energy and Buildings 23, 1996

"Regulamento Geral das Edificações Urbanas", Decreto-Lei nº 40/90 de 6 de Fevereiro

$Q = A\,Cd\,(2\,\Delta T\,H\,g) / (273 + T)$

where Q= air flow rate (m3/s); A (m2)= area of the window; Cd = 0.61; ΔT (ºC)= 12; H (m) = height of window measured from its centre ; g (m/s)= 9.81; T(º)= 42

Eco–efficient Mortars with Enhanced Mechanical, Durability and Bactericidal Performance

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University of Minho, Guimarães, Portugal

ABSTRACT: The cracking phenomena readily found in cement-based building structures not only paves the way for deleterious structural damage resulting from water penetration, but also degrades the aesthetic elements of the edifice. Lime-pozzolan mortars, however, demonstrate a promising alternative against the effects of weathering by accommodating expansion, contraction, temperature variability and moisture change. The present work identifies lime and metakaolin amounts, curing time and temperature as key factors affecting both the mechanical and durability properties of mortars using metakaolin-lime mixtures. In order to improve application-specific mortar performance along mechanical, durability and bactericidal lines, the present work employs a small percentage of activators that bring about effects in terms of bactericidity, strength gain enhancement and strength improvement at long curing time. Furthermore, this new mixture is especially suited for replacing cement-based mortars due to its specific characteristics of flexibility, water vapour permeability and environmentally sound, composition consisting of a lower measure of both embodied energy and manufacturing-related CO_2 emissions.

1 INTRODUCTION

Although the use of pozzolanic materials predates the invention of modern Portland cement by more than 2,000 years, its adoption has been largely abandoned due to long curing times necessary for sufficient strength gain. Hence, the accelerated rate of modern construction does not allow for their large-scale application.

The present research reports the development of metakaolin and lime mortars based on, evaluating the most efficacious proportion of the former and the latter. In addition, this work analyses temperature effects in the mixture curing process at 10º and 50ºC and the effect of incorporating different activators in the standard mixture. The evaluation procedure involved the characterization of utilized materials, the manufacture of specimens as well as compressive strength at different ages.

2 MATERIALS

Metakaolin is a pozzolan originating from kaolin, mineral clay traditionally used in the manufacture of ceramic products. The word kaolin owes its name to the mountainous region in China, known as Kao-Ling, where large kaolin deposits had been discovered and later exported to Europe (www.metakaolin.com, 2006 & Oliveira, Jalali, Fernandes and Torres, 2005). During heat treatment, kaolin loses two molecule of water: Metakaolin is an energy-free material that reacts chemically after the heat treatment it receives, exhibits a natural amorphous state and reacts with lime much like other pozzolans.

$$\mathbf{Al_2\,Si_2\,O_5\,(OH)_4 \longrightarrow Al_2\,O_3\,2Si\,O_2 + 2H_2O}$$

Much like fly ash or fume silica, metakaolin is ideal as a partial substitute for cement in concrete and mortar compositions thereby substantially reducing the amount of cement consumption. This specific application of metakaolin, moreover, covers structural concrete, lightweight concrete, pre-cast concrete, mortars and plasters while improving compressive and flexural strength, reducing permeability and efflorescence, offering better protection against chemical attack, , reducing fissures and improving the finishing, colour and appearance.

The metakaolin used in the current study was extracted from aggregate mining wastes that underwent heat-treatment. This process, moreover, led to the obtaining of an amorphous, alumino-silicate material that readily reacts with calcium hydroxide which, in turn, gave rise to cementitious materials.

The utilized metakaolin resulted from the transformation of kaolin at 600ºC in an industrial oven (referred to in this work as Mk600). This material is rich in silica (SiO_2) and alumina (Al_2O_3), has a pink coloration that is lighter than those found in red ceramics and has a density of 2564 kg/m^3. Particle size analysis indicated it to be 20% coarser than 0,212mm and 80% coarser than 0,106mm, with a maximum particle size of 0,425mm.

Lime mortars exhibit a very low rate of strength gain, are structurally vulnerable at early curing time, gain strength sufficient for most uses after a long curing period and are not water resistant. It is in light of the abovementioned reasons, therefore, that pozzolans are added to lime mixtures. The main benefits associated with the use of this type of lime-metakaolin mixture are not only functional and environmentally sound, but also much more cost efficient.. In functional terms, metakaolin improves workability and can, in some cases, reduce water content; increase mechanical properties boost permeability and enhance durability against chemical attacks. Furthermore, it substantially decreases the presence of cracks due to the low hydration heat and slow strength gain. From an economic standpoint, , pozzolans are less expensive than ordinary Portland cement, and have the added advantage of consuming less energy than OPC during the production phase. Furthermore, industrial by-products were used in this study in order to enhance environmental efficacy while lowering costs. When used as a cement substitute, pozzolans decrease energy consumption levels and lower CO_2 (Malhotra & Kumar, 2000) emissions.

Hydrated lime was used in this study with less than 1% water content, a maximum particle size of 0,2 mm and a bulk density at roughly 500 kg/m^3.

The activators consisted of calcium and sodium chlorides, sodium hydroxide, borax (tetraborate of hexahydrated sodium) and gypsum with a selection criteria consisting of their possible positive effects on mechanical strength, as well as on either the acceleration or retardation of mortar strength gain with respect to curing time. The amounts of activator used were 1 to 2% of the binder mass.

3 METHODOLOGY AND RESULTS

3.1 *Manufacture of Test Specimens*

Metakaolin-lime mixtures were prepared with 75% metakaolin and 25% lime with a water to binder ratio of 0,6 due to high water absorption of the components and wet earth consistency. A homogeneous mixture of dry metakaolin and lime was prepared in a laboratory mixer, to which water was then added to achieve a workable mixture. The mineral activators were dissolved in water and later added to the mixture.

Cylindrical test specimens were molded by static compaction (see figure 1). The specimens were 3cm in diameter and 3.7cm in height. The equipment allowed for the production of test specimens with constant mass. The manufactured specimens had a wet mass density of 40g (see figures 2 and 3) and a dry mass of 25g, corresponding approximately to an apparent dry density of 956kg/m^3.

The specimens were stored in a hermetically sealed conventional plastic box, with a small container of water and absorbent paper in order to maintain a relative humidity close to 100% without the specimen coming into direct contact with either water or air. By invoking this method, it was possible to uphold the necessary conditions for the curing process with a minimal interference of CO_2, and a consistently high level of relative humidity.

The obtained compressive strengths consisted of average test values for three specimens at each age.

Figures 1 and 2 – Hydraulic press and packing of specimens for tests

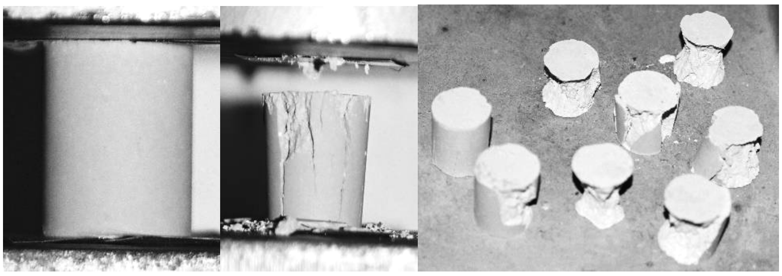
3.2 *The Effect of Lime Percentage in Metakaolin-Lime Mixtures*

In order to evaluate the effect of lime percentages on mixture performance (See the table 1), two distinct compositions of metakaolin-lime were analysed while holding the water to binder ratio constant and equal to 0,6. .

Table 1 – Mix Design of metakaolin-lime mixtures

Mixture	Materials	Quantities
	MK600	75%
M1	Lime	25%
	Water/Binder	0,6
	MK600	50%
M2	Lime	50%
	Water/Binder	0,6

The specimens were prepared by the static compaction method while keeping the specimen dry density constant.(See manufacture of test specimens in 3.1). The specimen showed a smooth surface with a light pink metakaolin coloration, satisfactory cohesion and rigidity for handling and a characteristic ceramic-like sound when tapped.



Figures 3, 4 and 5 – Specimens of metakaolin-lime mixtures: before and after the tests

Compressive strength tests showed fragile conic ruptures that are indicative of satisfactory cohesion (see figures 3-5). Results of compressive strength tests until the age of 90 days are presented in figure 6. From this, it may be seen that the M2 mixture, with 50% lime content, shows higher strength at the first two weeks. At 14 days the two mixtures, have approximately the same strength. From this age onwards, the M1 mixture presents a slightly superior strength.

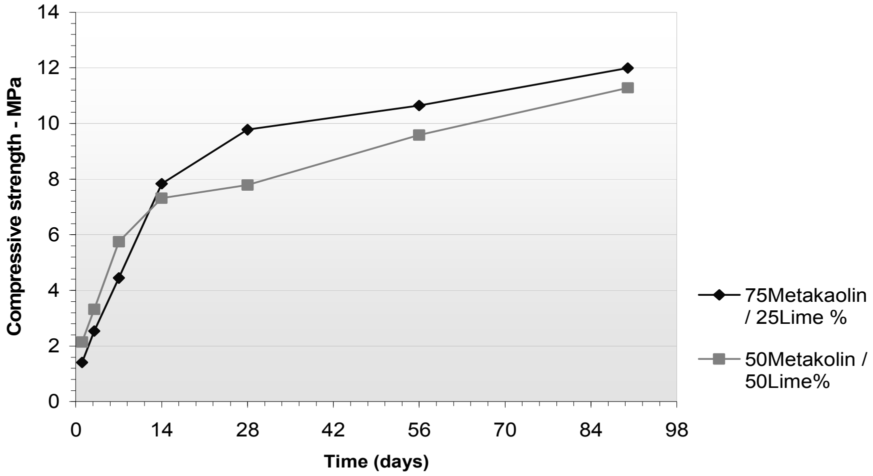


Figure 6 - Compressive strength of mortars using different metakaolin-lime contents

Results demonstrate that a higher amount of lime at early ages produces higher quantities of products from the pozzolanic reaction, while from two weeks onwards; the excess of lime inhibits the formation of further reaction products. Results obtained indicate that a mixture with 25% of lime and 75% of metakaolin has a better overall performance in terms of mechanical properties.

3.3 *Temperature Effect on Metakaolin-Lime Mixtures*

The rate of pozzolanic reaction does not only depend on the used composition, but also on the curing temperature. To evaluate the influence of curing temperatures on compressive strength, test specimens were molded with 75% of metakaolin, 25% of lime and small amounts of calcium chloride (2% of lime mass). Furthermore, specimens were cured at 10º, 20º, 30º, 40º and 50ºC, with a relative humidity of 100%.

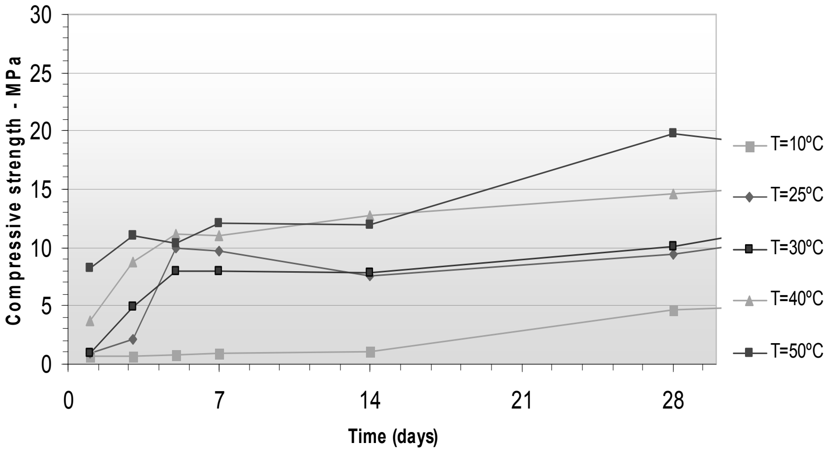


Figure 7 – Temperature effect on metakaolin-lime mixtures until 28 days

At 28 days and with a temperature of 10º C, compressive strength test results demonstrated there to be an induction period of up to 14 days during which compressive strength was constant. After this period, the strength gain began at a lower rate than specimens at higher curing temperatures. Specimens cured at 25 ºC also showed a small induction period of around two days. At curing temperatures higher than 25 ºC, this induction period was not discernible by means of strength testing. The overall strength gain of specimens followed the rates expected, i.e. higher rates of strength gain for higher curing temperatures. At 28 days, the strength achieved could be ordered with respect to curing temperature, i.e. the highest strength for 50 ºC, then 40ºC, while the lowest was for specimens cured at 10 ºC.

Figure 8 shows the effect of curing temperature up to 90 days of curing. The overall trend of strength gain was the same as 28 days. However, the strength gained at 90 days with a temperature of 50 ºC was significantly higher than that of other specimens. Furthermore, those cured at temperatures ranging from 10º to 40 ºC showed a compressive strength within a narrow range of 10 to 15 MPa, while specimens cured at 50 ºC showed 70% higher strength.

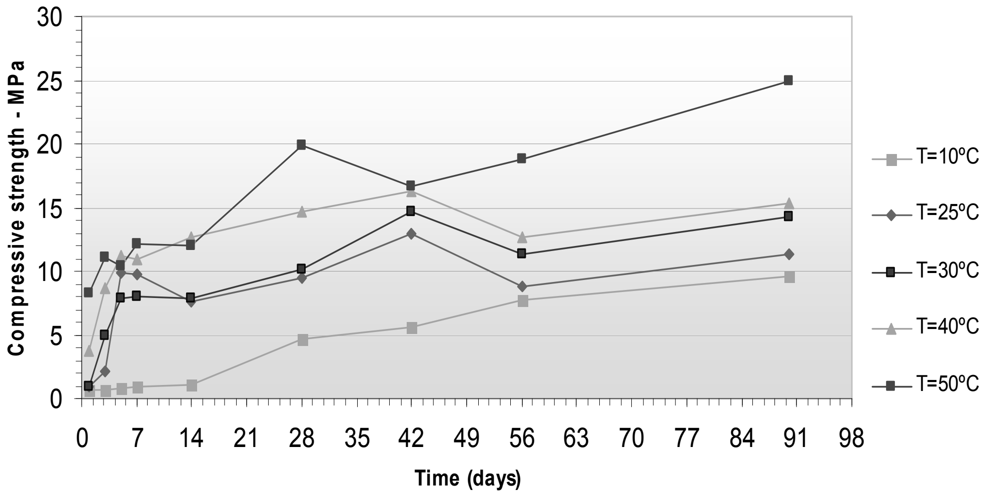


Figura 8 – Temperature effect on metakaolin/lime mixtures up to 90 days

3.4 *The Effect of Activators on Metakaolin-Lime Mixtures*

The research aim of improving the mechanical properties of the metakaolin/lime mixtures prompted the utilization of several mineral activators while evaluating their effects on overall compressive strength. Each activator was added in the mixture at a mass ratio of 2% (see Table 2).

Table 2 – Metakaolin/lime mixtures with activators

Mixture	Materials	Quantities
M	Mk600	75%
	Lime	25%
	Water/Binder	0,6
M3	Calcium Chloride (CaCl2)	2% of mixture
M4	Sodium Chloride (NaCl)	
M5	Sodium Hydroxide (NaOH)	
M6	Borax (Na2B4O710H2O)	
M7	Gypsum (CaSO4 2H2O)	

Compression test results until the age of 28 and 180 days are presented in figures 9 and 10.

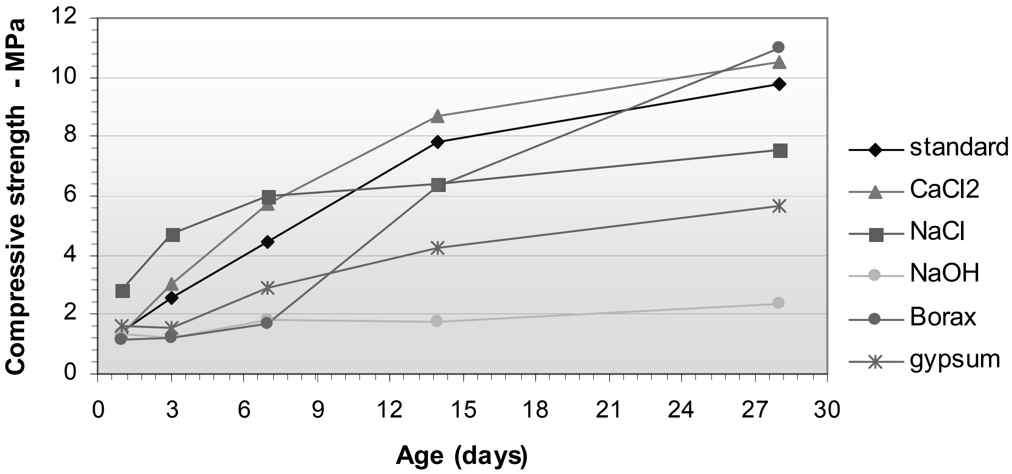


Figure 9 – The effect of activators on strength gain of metakaolin-lime mixtures until 28 days

It is readily clear that, compared with the mixture without activator; the composition with calcium chloride had a higher strength from the early age until 28 days. While strength gain of the borax containing composition was initially slower than that of the control specimen thereby, indicating a relatively long induction period, however, at 28 days curing times exceeded the values of all other compositions, including the control. The addition of sodium chloride only accelerated the strength gain during the first seven days, with a low rate of strength gain thereafter.

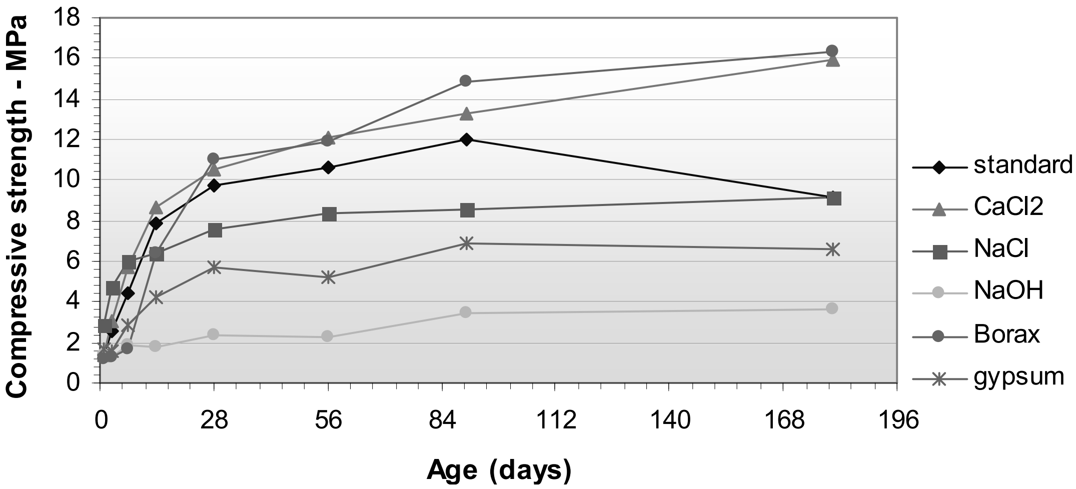


Figure 10 – Activator effects on metakaolin/lime mixtures until 180 days

The addition of sodium hydroxide and gypsum apparently did not have a positive effect on the strength gain of the mixtures. An unexpected decrease in the strength of the control mixture was registered at 180 days. The reasons for this are not clear at present.

For practical purposes, borax and calcium chloride seemed to be adequate for two different purposes. On the one hand, if high early strength was of immediate concern, calcium chloride would have been the option of choice. Conversely, if the long term strength was the desired end-result, then the use of borax would have been more appropriate.

4 CONCLUSIONS

The current research presented the effect of various factors influencing the strength gain of metakaolin-lime mixtures. The mix design with 75% metakaolin and 25% lime showed better mechanical performance at curing times longer than 14 days, which is attributable to the inhibition effect of lime in excess amounts.

Study of the use of activators indicated that a small percentage of calcium chloride exerts a beneficial effect on strength gain at all ages up to 180 days. The beneficial effect of borax incorporation, however, was apparent after 28 day curing period. Moreover sodium chloride only exerted an accelerating effect in the first days and reduced strength gain at longer ages.

It is worthy to note the strength gain delay time effect at 14 days when borax was used. . Strength gain, moreover, was quick to recover and became higher than all the other mixtures at 28 days curing time. This characteristic is especially appropriate for construction applications where some mixture flexibility is called for at early ages. This elevated strength gain also enables the proposed mixture to be used for buildings, or façades that are liable to cracks due to structural movements. On the other hand, when an early strength gain is deemed necessary, the chlorides are apparently the best option, especially the calcium chloride.

Consistent with expectations, study of the influence of curing temperature indicated that pozzolanic mixtures have a higher rate of strength gain at higher curing temperatures, while a decrease in hardening is seen at lower temperatures. Hence, it is apparent that these mixtures have a lower rate of strength gain during the winter when compared to summer period. .

This research highlights the effect of some factors that commonly affect the mechanical properties of mortars used for the rendering and laying of blocks and bricks. Results obtained can be used for practical purposes when specific characteristics are desired. Lime-pozzolan mortars are especially adequate when used with activators, has a significant environmental and economic advantage as compared to traditional OPC based mortars.

5 REFERENCES

Borge, Bjorn. The Ecology of Building Materials, Ed. Architectural Press of Reed Educational and Professional Publishing Ltd, 2000.

Komar, A. Building Materials and Components. Mir Publichers Moscow, 1974.

http://www.metakaolin.com, 2006.

Malhotra, V. M. and D. Kumar Mehta. Pozzolanic and Cementicious Materials. Advances in Concrete Technology UI. Gordan and Breach Publishers, 2000.

Oliveira Luíz, Saíd Jalali, José Miguel Fernandes, Elvira Torres; L'emploi de métakaolin dans la production de béton écologiquement efficace, Mater. Struct. (277), RILEM publications, 2005.

Structural Concrete with Incorporation of Coarse Recycled Concrete and Ceramic Aggregates

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ABSTRACT: The growing difficulty in obtaining natural coarse aggregates for the production of concrete, associated to the environment issues and social costs that the uncontrolled extraction of natural aggregates creates, led to a search for feasible alternatives. One of the possible paths is to reuse Construction and Demolition Waste (CDW) as aggregates to incorporate into the production of new concrete.
Therefore, a vast and detailed experimental phase was implemented at Instituto Superior Técnico, which aimed at determining the viability of incorporating coarse aggregates from concrete and ceramic brick wall debris, in the production of a new concrete, with properties acceptable for its use in new reinforced and pre-stressed concrete structures. The experimental campaign was divided in three distinct stages, in which different compositions were studied by adding controlled percentages of recycled coarse concrete aggregates and recycled coarse ceramic plus mortar particles, and the main mechanical, deformability and durability properties were quantified, by comparison with a conventional concrete.
In the present paper these results are presented in terms of mechanical performance of concrete, namely compressive and splitting tensile strength, abrasion resistance and modulus of elasticity.

1 INTRODUCTION

The use of products resulting from the demolition of concrete structures as aggregates for the production of new concrete is a theme that has been treated with growing interest within the international scientific community. Even though some work has already been developed, there are still many doubts in what concerns the use of structural concrete with recycled aggregates.

The present paper presents the results of an experimental campaign developed at Instituto Superior Técnico where the technical viability of replacing natural coarse aggregates with coarse aggregates recycled from concrete and rendered ceramic partition walls was studied.

Various compositions were tested with different replacement ratios: 12.5, 25, 50 and 100% for coarse aggregates recycled from concrete (AGRB); 6.25, 12.5, 25 and 50% for coarse aggregates recycled from bricks and adhered mortar (AGRC); and replacement with both materials 6.25% AGRC-12.5% AGRB, 12.5% AGRC-25% AGRB e 25% AGRC-50% AGRB. Every concrete mix with coarse recycled aggregates (BAGR) was compared with a conventional reference concrete (BR) in terms of mechanical strength and durability.

2 EXPERIMENTAL CAMPAIGN

2.1 *Stages of the campaign*

The first stage of the experimental campaign fundamentally aimed at calibrating the various compositions tested (considering the various ratios of incorporation of recycled aggregates) in order to obtain a constant slump value using the Abrams cone of 80 ± 10 mm.

In the second stage of this campaign, it was necessary to determine the water absorption evolution of the recycled aggregates due to the brisk reductions in the workability of mixes with a high percentage of recycled aggregates. This process led to a slight increase in the slump value as compared with the first stage (around 87 mm) but still acceptable for this purpose.

This stage allowed the elimination of those mixes that according to a performance-based analysis did not fulfill the following criteria, in order to obtain structural concrete with enhanced durability:

1. reduction in compressive strength lower than 15% in comparison with the reference concrete (BR);
2. increase in shrinkage at 90 days lower than 30% in comparison with the BR;
3. increase in water absorption by capillarity lower than 30% in comparison with the BR;
4. increase in water absorption by immersion lower than 30% in comparison with the BR.

The third stage of the experimental campaign depended on the results of the second stage and allowed further investigating the mechanical, deformability and durability related characteristics of the mixes that fulfilled the criteria mentioned using different tests. Only the results concerning the mechanical performance of the BAGR selected are presented.

2.2 *Concrete mixes analysed*

In Tables 1 to 3 the composition of all mixes tested is presented. The water that was added to compensate the higher absorption of the recycled aggregates was the first in the mixer, immediately after the aggregates, as well as a third of the hydration water. After 15 minutes of pre-saturation the remaining materials were added.

2.3 *Compressive strength*

In order to determine the compressive strength of the various concrete mixes produced in the second and third stages, the European Norm EN 12390-3 of December 2001 [1] was used.

The average results obtained at 28 days (after curing under controlled conditions) for the 6 specimens tested per mix in the second stage are presented in Table 4.

Table 1. Composition of the mixes with concrete recycled aggregates (AGRB) (/ m^3)

	BR	B12.5B	B25B	B50B	B100B
Replacement ratio (%)	0	12,5	25	50	100
Cement CEM II 42,5 R (kg)	446	446	446	446	446
Water (l)	192	194,5	197,0	202,1	212,3
w/c ratio	0,43	0,44	0,44	0,45	0,48
Effective w/c ratio	0,43	0,43	0,43	0,43	0,43
Fine aggregates (natural sand) (kg)	426	426	426	426	426
Natural coarse aggregates (kg)	1111,8	972,8	833,9	555,9	0
Recycled coarse aggregates (kg)	0	133,4	266,8	533,6	1067,3

Table 2. Composition of the mixes with bricks and mortar recycled aggregates (AGRC) (/ m^3)

	BR	B6.25C	B12.5C	B25C	B50C
Replacement ratio (%)	0	6,25	12,5	25	50
Cement CEM II 42,5 R (kg)	446	446	446	446	446
Water (l)	192	197,2	202,4	212,8	233,6
w/c ratio	0,43	0,44	0,45	0,48	0,52
Effective w/c ratio	0,43	0,43	0,43	0,43	0,43
Fine aggregates (natural sand) (kg)	426	426	426	426	426
Natural coarse aggregates (kg)	1111,8	1042,3	972,8	833,9	555,9
Recycled coarse aggregates (kg)	0	58,9	117,7	235,4	470.9

Table 3. Composition of the mixes with concrete, bricks and mortar recycled aggregates (AGRB and AGRC) (/ m^3)

	BR	B6.25C12.5B	B12.5C25B	B25C50B
Replacement ratio (%)	0	25	50	100
Cement CEM II 42,5 R (kg)	446	446	446	446
Water (l)	192	199,7	207,4	222,9
w/c ratio	0,43	0,45	0,47	0,50
Effective w/c ratio	0,43	0,43	0,43	0,43
Fine aggregates (natural sand) (kg)	426	426	426	426
Natural coarse aggregates (kg)	1111,8	903,3	694,9	277,9
Recycled coarse aggregates (kg)	0	192,3	384,5	769

Table 4. Average compressive strength and difference from the BR (2nd stage)

	f_{cm} (MPa)	Δ
BR	47,51	-
B12.5B	46,60	-1,43
B25B	45,86	-2,99
B50B	49,79	5,34
B100B	49,60	4,93
B6.25C	48,01	1,56
B12.5C	44,07	-6,78
B25C	44,78	-5,27
B50C	36,12	-23,58
B6.25C12.5B	46,29	-2,08
B12.5C25B	44,96	-4,08
B25C50B	45,81	-3,09

These results show that for the mixes with incorporation of AGRB only compressive strength is not affected by this change in their composition (Figure 1). The same conclusion can be drawn for concrete mixes with simultaneous incorporation of AGRB and AGRC (only low ratios) (Figure 2). The main reason for this is the high content in the recycled aggregates of cement (hydrated and non-hydrated) with a high mechanical strength (CEM II 42,5R), that increases the effective content of cement in the mix when compared with the theoretical value.

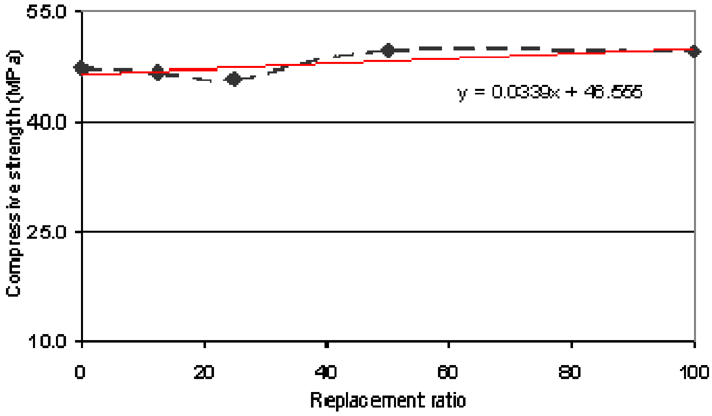

Figure 1. Compressive strength of concrete *versus* AGRB replacement ratio

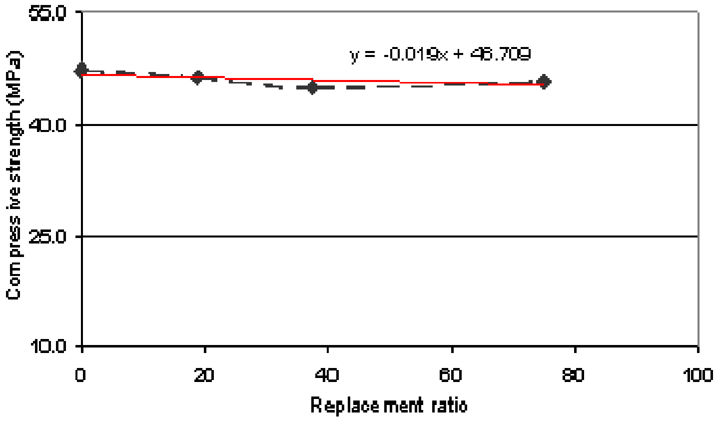

Figure 2. Compressive strength of concrete *versus* AGRB and AGRC replacement ratio

On the contrary, the incorporation of high ratios of AGRC leads to a significant loss of mechanical strength (Figure 3), mostly due to the smaller resistance of the ceramic material itself.

2.4 *Spliting tensile strength*

The tensile strength of concrete is a paramount parameter in its mechanical performance. The ultimate tensile stress may be obtained using various methods: pure tension, flexural strength and splitting tensile strength (as in this campaign).

In the third stage of this experimental campaign, 3 specimens of each mix (the ones used in the non-destructive modulus of elasticity test) were tested. The test was performed according to European Norm EN 12390-6, equivalent to Portuguese Norm NP EN 12390-6 [2].

The test consists in positioning cylinders with a diameter of 150 mm and a height of approximately 300 mm after rectification under and centred with a hydraulic press. Thus the load is radial guarantying that its plan of action passes through the cylinder centre (Figure 4). The load was applied at a constant ratio of between 0,04 and 0,06 MPa/s in terms of stress.

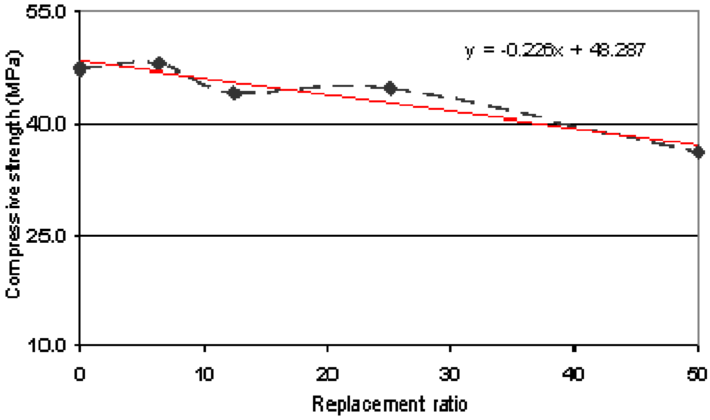

Figure 3. Compressive strength of concrete *versus* AGRC replacement ratio

After failure (Figure 5), the maximum load (F) is registered and the splitting tensile strength, $f_{ct,sp}$, is obtained by:

$$f_{ct,sp} = \frac{2 \times F}{\pi \times L \times d}$$

in which L is the height of the cylinder (mm) and d its diameter (mm). The results obtained are summarized in Table 5.

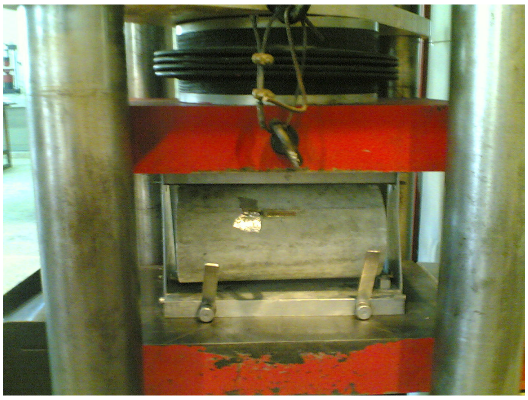
Figure 4: Splitting tensile strength test using a hydraulic press


Figure 5: Failure surface of a specimen through its centre

Concrete tensile strength is affected by the nature of the aggregate surface (related with its degree of adhesiveness to the cementitious mortar matrix) and by the latter's ultimate tensile stress. Thus follows the lesser tensile strength of the mixes with incorporation of AGRC as compared with those with AGRB, independently of the aggregates replacement ratio.

Table 5: Splitting tensile strength and difference from the BR (3rd stage)

	Specimen 1	Specimen 2	Specimen 3	Average (MPa)	Δ (%)
BR	3,41	3,13	3,13	3,23	
B50B	3,79	2,87	3,03	3,23	0,2
B100B	3,50	3,05	2,70	3,08	-4,5
B25C	3,07	3,07	2,89	3,01	-6,6
B50C	2,58	2,55	2,61	2,58	-20,1
B12.5C25B	2,62	3,05	2,28	2,65	-17,9

For mixes with double incorporation of recycled aggregates up to a limit of 12,5% of AGRC and 25% of AGRB, the maximum loss of tensile strength to the reference concrete is 17,9%, very similar to the one of the modulus of elasticity of the same threshold mix (see §2.6).

When the cement content and the effective water / cement ratio are maintained, the tensile strength is hardly affected (see the result of mix B50B) from the BR to mixes with AGRB (for total replacement, mix B100B, a loss of only 4,5% is registered) probably due to an increase in the surface roughness of the AGRB.

For mixes with incorporation of AGRC, the tensile strength decreases almost linearly with the replacement ratio (Figure 6), with a maximum reduction to the BR of 42,2% (for total replacement). Ana Pereira [3], in her experimental campaign where natural coarse aggregates were replaced with ceramic aggregates only, when testing in flexion 180 x 400 x 40 mm concrete slabs, reached similar results, thus confirming that:

- tensile strength decreases as the ratio of ceramic and mortar aggregates increases, i.e. these aggregates provide a lower contribution to concrete's tensile strength than natural aggregates;
- this decrease is practically linear, given the high correlation ratios.

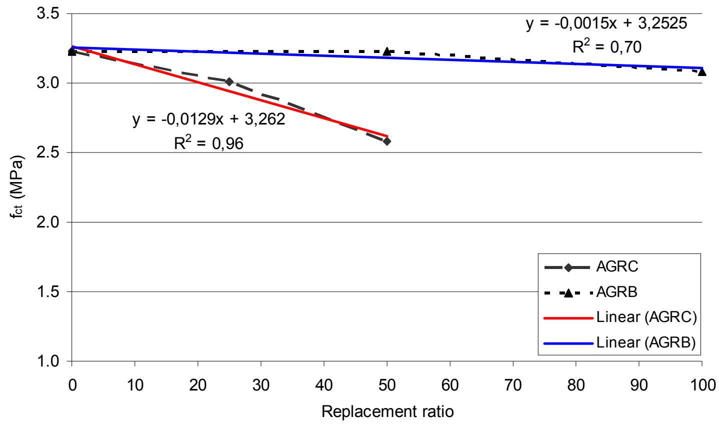

Figure 6: Splitting tensile strength of concrete *versus* AGRB and AGRC replacement ratio

2.5 *Modulus of elasticity*

The determination of the modulus of elasticity aimed at characterizing concrete in terms of deformability, an important feature for structural concrete.

The test to determine the modulus of elasticity was made according to norm LNEC E 397 - "Concrete: determination of the modulus of elasticity in compression" [5]. Specimens are cylinders with 150 mm diameter and 300 mm height.

For each mix (BR, B50B, B100B, B25C, B50C, B12.5C25B) 3 specimens were tested during the third stage of the experimental campaign by loading them up to 30% of the compression failure stress of the material. Two extensometers were glued to opposite faces of each specimen. Loading was concentric with the specimens (Figure 8), leading to differences registered in the two extensometers no greater than 10%, at the risk of repeating the whole procedure.

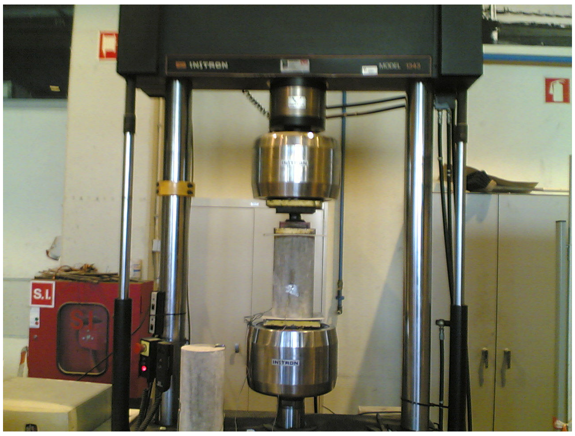

Figure 8: Modulus of elasticity test in a hydraulic press

Three cycles of loading and unloading were performed. An initial stress of 0,5 to 1,0 MPa was applied and the correspondent strain (ε_s) was registered. Stress was then increased gradually and continuously at a rate of 1,0 MPa/s until the ultimate value (approximately $f_{cm}/3$) was reached. Final results are presented in Table 7.

Table 7: Modulus of elasticity values and difference from the BR (3rd stage)

	Specimen 1	Specimen 2	Specimen 3	Average (GPa)	□ (%)
BR	43,5	38,7	40,5	40,9	
B50B	35,8	37,9	36,5	36,7	-10,2
B100B	30,2	27,1	28,5	28,6	-30,0
B25C	40,2	30,0	33,2	34,5	-15,8
B50C	29,7	32,4	33,0	31,7	-22,2
B12.5C25B	34,2	35,5	33,1	34,3	-16,2

The module of elasticity of the BAGR are lower than the one of the BR and the more so the lesser the compactness of the recycled aggregates, i.e. the greater the percentage of cement paste adhered in the recycled aggregates, which has lower stiffness than natural stone. This is aggravated for ceramic aggregates due to their much lower bulk density.

The stiffness losses to the BR of 10% for a maximum incorporation of 50% AGRB and of 15,8% for a maximum incorporation of 25% AGRC are nevertheless very promising results for this type of concrete, showing that their mechanical capacity is affected to a limited degree unlike it is sometimes stated.

Figure 9 also shows that the decrease in the modulus of elasticity with the replacement ratio is substantially higher for concrete with AGRC than with AGRB for the same ratio. This situation is due both to the lower bulk density of the ceramic material and to the worse characteristics of the adherent mortar, namely in terms of the cement used in its production (CEM I 32,5 R).

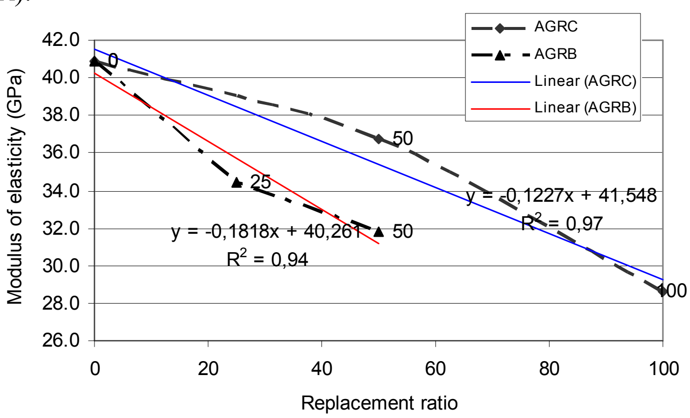

Figure 9: Modulus elasticity of concrete *versus* AGRB and AGRC replacement ratio

3 CONCLUSIONS

The results obtained indicate that the replacement of natural coarse aggregates (AGN) with coarse aggregates recycled from concrete (AGRB) and from ceramics and mortars (AGRC) is feasible, since:

- compression strength class of concrete with recycled aggregates (BAGR) is not affected by the simultaneous incorporation of AGRB and AGRC, up to a maximum ratio of 25% AGRC and 50% AGRB, or the incorporation of 100% AGRB, by comparison with the reference concrete (BR) with natural aggregates only;
- tensile strength of concrete depends on the nature and surface type of the recycled aggregate, the content of binder (hydrated and non-hydrated) in the mix and the effective water / cement ratio; therefore, for BAGR with AGRB only this strength was not much affected by the replacement ratio;
- modulus of elasticity is affected to a small scale by the incorporation of recycled aggregates up to a maximum percentage of 50% AGRB and 25% AGRC; thus decrease is due to the lower compactness of these aggregates as compared with AGN and the higher deformability of the adherent cement paste; for simultaneous incorporation of AGRB and AGRC up to a maximum ratio of 25% and 12,5% respectively, a reduction of 16,2% in the modulus of elasticity was registered, a value that confirms the potential of both these types of recycled aggregates for structural concrete;
- from all the tests and from a mechanical performance point of view it can be stated that I t is technically safe to replace the coarse part of the natural aggregates of a concrete with recycled aggregates from concrete up to a 50% ratio and of ceramics and mortars up to 25%.

4 ACKNOWLEDGEMENTS

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5 REFERENCES

[A] NP EN 12390-3 “Testing hardened concrete - Part 3: Compressive strength of test specimens”, 2001.

[B] NP EN 12390-6 “Splitting tensile strength of specimens” *(in Portuguese)*, CEN, Lisbon, 2003.

[C] *Pereira, A. S.* “Use of recycled coarse ceramic aggregates in the production of concrete” *(in Portuguese)*, Masters Thesis in Construction, Instituto Superior Técnico, Lisbon, 2002.

[D] DIN 52108 “Testing of inorganic non-metallic materials: wear test with the grinding wheem according to Boehme” *(in German)*, DIN, Germany, 2002.

[E] LNEC E397 “Concrete: determination of the modulus of elasticity in compression” *(in Portuguese)*, Lisbon, 1993.

An energy efficient solution to mitigate heat islands and reduce cooling energy loads

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ABSTRACT: The passive cooling technique proposed in this study is the use of cool materials with high solar reflectance and infrared emittance values. A simulation study has been carried out using TRNSYS, to assess the impact of using cool materials on cooling energy loads and thermal comfort conditions in residential buildings in cooling dominated cities. The results show that increasing roof solar reflectance reduces cooling demand and improves indoor thermal comfort conditions. Furthermore a modeling study has been undertaken using the 'urbanized' version of MM5 trying to analyze the impacts of large-scale increases in surface albedo by the city scale application of cool materials, on ambient temperature. It was found that large-scale increases in albedo could lower air temperatures by 2°C. The results of this study can help to promote the adoption of high albedo measures in building energy codes and urban planning regulations.

1 INTRODUCTION

The heat island effect is becoming increasingly more intense in urban areas around the world. Some of its consequences are the increase in energy demand, the acceleration of the formation of harmful smog and human thermal discomfort and health problems by intensifying heat waves over cities (Oke et al., 1991;Santamouris, 2001; Cartalis et al., 2001; Stathopoulou et al., 2005; Santamouris, 2006). The mitigation of the heat island effect can be achieved by the use of cool materials that are characterized by high solar reflectance and infrared emittance values. These two properties are the main factors controlling the temperature of a surface (Bretz and Akbari, 1997). Increasing either reflectance and/or emittance lowers a surface' s temperature. At building scale this results in decreasing the heat penetrating into the building, and therefore in lowering cooling loads if it is an air-conditioned building, or in more comfortable thermal conditions if the building is not air-conditioned. At city scale it contributes to decrease the temperature of the ambient air as heat convection intensity from a cooler surface is lower. During the summer, this results. (Rosenfeld et al. 1996, Taha et al. 1999).

Many experiments have been undertaken demonstrating the effectiveness of cool roofs in reducing cooling-energy use in residential buildings. Akbari et al. 1997 measured cooling energy savings of about 2.2 kWh/day from changing the roof albedo of a residence in Sacramento, California from 0.18 to 0.73. Reductions in total and peak air-conditioning load of approximately 5% were measured for two identical white (SR= 0.75) compared to gray (SR= 0.30) and silver (SR= 0.50) roofed scale model buildings in Tucson Arizona (Simpson and McPherson 1997). In addition to field studies, computer simulations of cooling energy savings from an increased roof albedo have been documented for residential buildings. A simulation study performed for two mild and hot climates, showed that as the absorbtance varies from 1 to 0, the total energy load decreases by 32% and 47%, respectively for not insulated buildings and by 26% and 32% for insulated buildings (Shariah et al. 1998). A study on the energy efficient envelope design for high-rise apartments in Hong Kong showed that a 30% reduction in solar absorptance can achieve 12% saving in annual required cooling energy (Cheung et al. 2005). Using cool roofing colored materials it was demonstrated that increasing the roofs reflectance from 0.08 to 0.3 and 0.5 decreases the consumed energy by 15% and 30%, respectively in Miami and Dallas (Miller et al. 2004)

Direct field observations verify the impact of high albedo surfaces on near surface air temperatures. Experimental measurements were carried out at White Sands Monument in New Mexico, an area that has a high albedo (≈0.6) because its surface is composed of white gypsum and little vegetation, and also at the surrounding desert area, which has an albedo of 0.26. Results have shown that in the morning hours, the air over White Sands Monument was by 3°C cooler than the air over the surrounding dark surface. It was also found that the air remained cooler throughout daytime hours, but the amount of cooling was reduced later in the day because of increased upwelling (Fishman et al. 1994). Sailor (1995) showed by means of 3D meteorological simulations that increasing the albedo over downtown Los Angeles by an average 0.08 decreased summertime temperature by as much as 1.5°C. Numerical simulations undertaken by Taha (1997) found that increasing the albedo of the California' s South Coast Air Basin by 0.13, simulated reductions of averagely 2°C. In another mesoscale modeling study Taha et al. (2000 and 2002) showed that cool-city strategies can reduce urban air temperatures by a typical 1-2K for the case of three US cities and by 0.5 -1°C for the case of Greater Toronto Area, Canada.

This study aims to evaluate by means of simulation the potential energy savings and the impact on thermal comfort from the use of cool roof coatings in residential buildings in various climatic conditions worldwide. Furthermore the impacts of large-scale increases in surface albedo on ambient temperature were investigated trying to analyze the Urban Heat Island (UHI) effect over Athens, Greece, a dense populated city. Numerical simulations were performed by the 'urbanized' version of the non-hydrostatic PSU/NCAR Mesoscale Model (MM5, version V3-6-1). Two scenarios of moderate and high increased albedo have been studied.

2 EXPERIMENTAL ASSESSMENT OF COOL MATERIALS

For this study the estimates of the potential for altering the urban albedo of Athens are based on a two-dimensional analysis and do not consider vertical surfaces like walls. Furthermore, only the albedo of building structures (rooftops) was changed. The same applies for the simulation study for the estimation of cooling energy loads reduction. For this reason, only materials that can be used on building rooftops have been considered. A number of white or light colored materials (e.g. cool surface coatings, reflective tiles, concrete and conventional asphalt with white aggregate) are currently commercially available for rooftops having high solar reflectance values ranging from 0.4 to 0.85. The thermal emissivity of these materials was measured to be about 0.9. (Berdahl et al. 1997, Synnefa 2006). Surface temperature measurements have demonstrated that a cool coating can reduce a concrete tile's surface temperature by 7.5°C and it can be 15°C cooler than a silver gray coating (Berdahl et al. 1997, Synnefa 2006). Furthermore, new cool colored materials that are highly reflective in the near infrared, are being developed using specialized infrared reflective pigments, for the cases where the aesthetics of darker colors is preferred or for the cases where the use of white colored products produces glare problems (Akbari et al. 2004, Synnefa et al. 2007). Cool colored materials, absorb in the visible range, in order to appear having a specific colour, but they are highly reflective in the near infrared part of the electromagnetic spectrum to maintain a high solar reflectance. This is very important considering the fact that about half of all solar power arrives as invisible near infrared radiation. Experimental measurements have demonstrated that the maximum difference between the solar reflectance of a cool and conventional color matched coating was found to be 0.22 with a corresponding surface temperature difference of 10.2 °C (Synnefa et al. 2007). Another study reports that the solar reflectance of commercially available products has increased to 0.30–0.45 (Akbari et al. 2005).

3 ESTIMATION OF THE IMPACT OF USING COOL MATERIALS ON COOLING ENERGY LOADS AND THERMAL COMFORT

In order to estimate the effect of the use of cool white and colored materials on the residential energy load, simulations were performed for 5 cooling dominated cities around the world: Abu Dhabi, Athens, Miami, Cairo and Sydney. TRNSYS thermal simulation software (TRNSYS) was used for the simulations. The calculations were performed with an hourly time step. The meteorological data were taken from the METEONORM database (METEONORM). The base case building used in the simulation is a single story, flat roof house with a roof area of 100 m^2. It is nondirectional, in the sense that its length and width are equal (10 m). Its height is assumed to be 3 m. Each wall has a glazing of 4 m^2 (13.3% of the wall area), a U-value of 5.8 W/m^2 K and it is well shaded (external shading factor 0.7). The U-value of the walls was considered to be 2.2 W/m^2 K and the U-value of the roof equal to 0.84 W/m^2 K. Infiltration rate was set equal to 0.8 ach. Regarding internal gains, the heat input per person was considered according to ISO7730, while for the artificial lighting and any other equipment it was assumed that 50% of the input is contributed to the place as convective heat and the 50% as radiative. This building type may not necessarily be representative of the typical house in all the tested locations. However, the purpose is to report the cooling energy savings and potential wintertime penalties from changing the roof's solar reflectance comparatively. The thermostat set point temperatures for cooling and heating was set to 26 and 21°C respectively. Three different values of roof solar reflectance were simulated based on the experimental results for the cool and cool colored materials described above. For the base case the solar reflectance was considered to be 0.2. The increased values of solar reflectance due to the use of cool coatings were (a) a moderate 0.6 and (b) an extreme value of 0.85. The first scenario of albedo increase also accounts for the effects of albedo reduction due to weathering, ageing, dust accumulation and soiling of a roof with an initial albedo value close to 0.85. The infrared emittance was considered to be 0.9. Furthermore, for estimating the effect of cool coatings on thermal comfort conditions in the building, the above simulations were repeated but for the building running under free floating conditions.

The cooling loads were calculated for the reference case (SRroof=0.2) and the two increased solar reflectance scenarios representing buildings using cool roofing materials. The results (corresponding to a roof u-value of 0.84 $W/m^2/K$) are presented in table 1.

It should be pointed out that the values mentioned in this part of the study depend on the building characteristics and therefore are only indicative. As expected increasing roof reflectance results in reduced summer cooling loads. The decrease in the cooling loads for an increase in roof solar reflectance by 0.4 varies between 13 and 29 kWh/m^2 and for a higher increase by 0.65 between 21 and 48 kWh/m^2

Table 1: The calculated cooling loads for the base case (roof solar reflectance equal to 0.2) and the two increased albedo cases (ΔSR1=0.4 and ΔSR2=0.65)

Place	Cooling load (kWh/m^2) Base case (SR=0.2)	Cooling load (kWh/m^2) Increased albedo case 1 (SR=0.6)	Cooling load (kWh/m^2) Increased albedo case 2 (SR=0.85)
Abu Dhabi	265.4	236	217
Miami	117.7	92.4	76.7
Cairo	104.5	84.6	72.4
Athens	58	43.3	34.6
Sydney	37.7	24.3	16.8

In order to estimate the heating penalty from increasing solar reflectance heating loads were also calculated. Figure 1, depicts the changes in cooling and heating loads resulting from an increase in roof solar reflectance of 0.65. The figure shows that the potential savings are greater in cooling season-dominated climates. For the building chosen and the climates examined in this study, the decrease in cooling loads always exceeded the increase in heating load. We can therefore conclude that increasing the solar reflectance of a roof is typically more beneficial for hot climates where cooling load dominates most of the year.

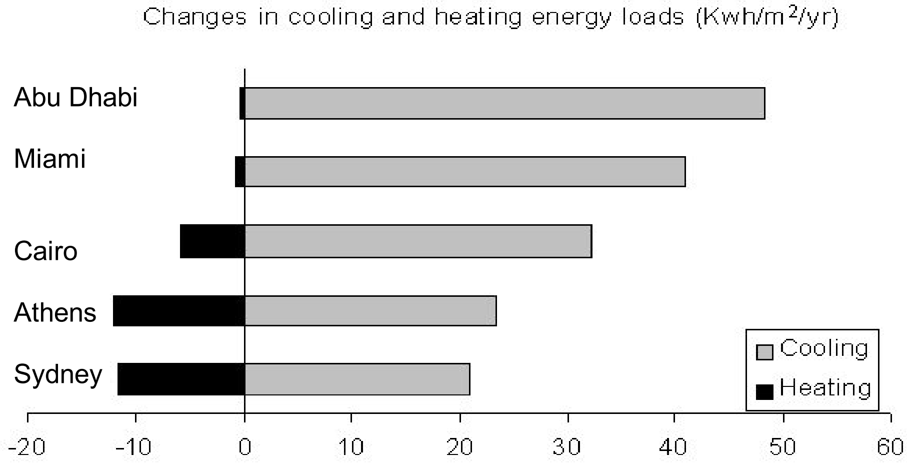

Figure 1: Cooling and heating load changes for a change in roof solar reflectance of 0.65.

In order to evaluate the effect of climate on thermal comfort conditions inside the building the number of hours that the indoor temperature exceeds 27°C was calculated. This threshold temperature was chosen based on the ASHRAE standard 55-1992 on thermal comfort conditions. According this standard the acceptable temperature range for summer conditions is 23.3°C to 27.7°C and the chosen value is close to the upper limit of the range. The calculated hours of discomfort for the conventional building and the two buildings using cool coatings (SR1=0.6 and SR2=0.85), for the threshold value, are presented in table 2. It is evident that increasing the roof solar reflectance reduces significantly the hours of discomfort.

Table 2: The calculated number of hours with the indoor temperature exceeding 27º C

Hours above a threshold indoor temperature: 27°C			
Place	Base case	ΔSR 0.4	ΔSR 0.65
Abu Dhabi	2300	1485	1007
Miami	5739	5441	5229
Cairo	2384	1762	1250
Athens	3254	2729	2352
Sydney	2190	1758	1436

Table 3 gives the calculated maximum indoor temperatures for the conventional house and the two cases of increased roof solar reflectance. For the first scenario the maximum temperature decrease varies between 0.8 and 2 8C and for the second between 1.2 and 3.7 8C. It can be concluded that the use of cool roofing materials can contribute to the improvement of indoor thermal comfort conditions by decreasing the hours of discomfort and the maximum temperatures.

Table 3: The calculated maximum indoor temperature for the base case and the increased roof solar reflectance cases

	Maximum indoor temperature (°C)			Decrease in maximum indoor temperature (°C)	
Place	Base case	ΔSR 0.4	ΔSR 0.65	ΔSR 0.4	ΔSR 0.65
Abu Dhabi	36.1	34.4	33.2	1.7	2.9
Miami	46.2	44.3	43.0	2.0	3.2
Cairo	36.6	34.6	33.3	2.0	3.3
Athens	39.6	37.9	36.7	1.8	2.9
Sydney	39.1	37.5	36.4	1.6	2.7

4 ASSESSMENT OF THE POTENTIAL OF COOL MATERIALS TO CONTRIBUTE TO THE MITIGATION OF THE HEAT ISLAND EFFECT IN ATHENS

Numerical simulations were performed by the non-hydrostatic, mesoscale model developed by PSU/NCAR, known as MM5, version V3-6-1, (Grell et al., 1994) with the modified MRF-urban PBL scheme (Dandou et al., 2005). The MM5 numerical simulations were performed by applying the 25-category USGS land use classification scheme in order to provide the land-cover data for the model domains. The initial and lateral boundary conditions for the outermost domain were provided by a coarser numerical weather prediction model, the European Center for Medium range Weather Forecast (ECMWF). The numerical simulation was supplemented by information derived from satellite image analysis. In particular, one Landsat-5/TM image, acquired on the 13th May 2003 covering the greater Athens area, has been digitally processed and analysed in order to extract all urban elements which are greater than the size of the higher spatial resolution pixel (30 m). In this procedure, an updated and more realistic representation of the urban expansion was obtained. This detailed information was used in the MRF-urban scheme in order to construct new fields for various parameters such as the albedo, the roughness length and the semi-empirical coefficients for the heat storage flux within the urban limits of the city, by applying an aggregation procedure. This was achieved by providing to each 30 m pixel (from the higher resolution domain) literature values (e.g. Grimmond et al., 1991; Grimmond and Oke, 1999) for the various parameters, according to the above urban categories. Thereafter, these values were aggregated to each 4 km^2 and 0.45 km^2 grid cells in the MM5 modeling domains using an area-weighting scheme. Thus, the new values of the parameters, in the modified version, reflect the presence of all the areas with different specifications within each 4 km^2 and 0.45 km^2 grid cell and are not related to a fixed land use type.

The simulated domains covered the extended areas of Europe, Greece, Attica peninsula and the city of Athens respectively. The spatial resolution for the innermost nested domain (the city of Athens) was 0.67 x 0.67 Km^2 (Figure 1A). Simulations have been performed for a clear and warm summer day, the 15th August 2005.

Based on the experimental results reported in the second paragraph the base case albedo for building structures was considered 0.18 (Figure 2B) and two scenarios of increased albedo were chosen for the simulations: a moderate and feasible increase in the buildings structure albedo of 0.45 (albedo =0.63) and an extreme case were the albedo of building structures is considered 0.85 (Figure 2C and D).

While all the meteorological parameters are affected by changes in surface albedo, only the effect on temperature is being discussed in this paper. The impacts of high albedo primarily influence the regions that underwent the simulated increase in albedo.

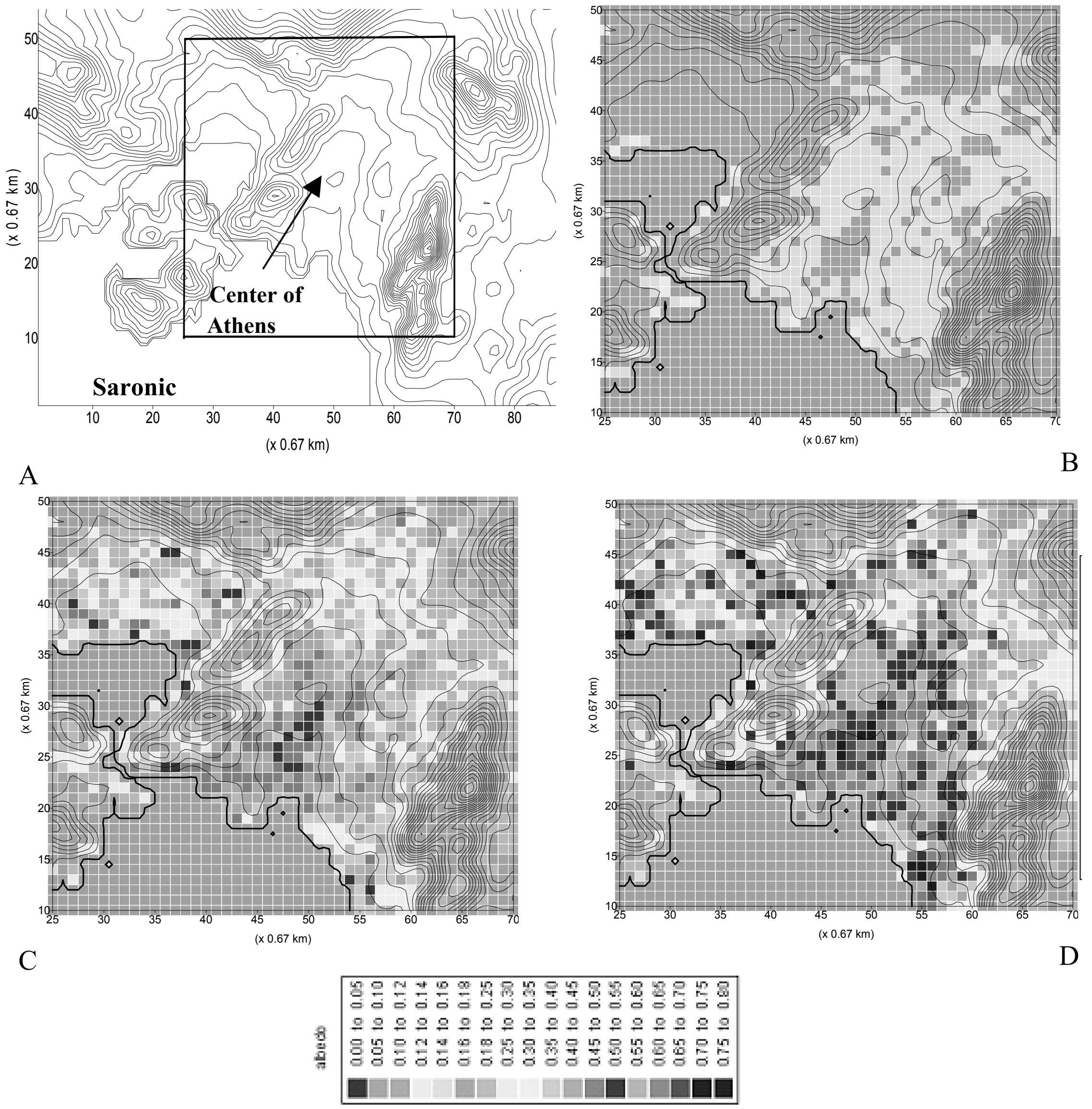

Figure 1: A)Topography contour lines at 50 m intervals of the fourth nested domain. The modeling domain with B)the base case scenario (building structures albedo a_{bs}=0.18) C) the moderate increase in albedo scenario (a_{bs}=0.63) D) the high increase in albedo scenario (a_{bs}=0.85)

The simulations suggest that the urban areas (as well as other suburban and rural areas) are generally cooler than in the base case. The impact of albedo increase is higher at 12p.m. to 3p.m. More specifically, for the moderate increase in albedo case, the temperature depression at 2m height at 14p.m.LST varies between 0.5 and 1.5°C (Figure 2A). If the albedo is further increased (extreme albedo case), then the temperature difference from the base case varies between 1-2 °C, with individual depressions as high as 2.2°C (Figure 2B). Most of the temperature depression occurs in the central and central east basin. The changes in air temperature that are observed in the majority of the areas of the modeling domain are due to the increase of the surface albedo, which results in less solar gains for the surface. During the night, the temperature remains in general unchanged between the base case and the modified albedo scenarios

In this study only the albedo of building structures has been increased. The impact of high albedo on air temperature would have been even greater if the albedo of roads and pavements had also been increased. Nevertheless, a decrease in air temperature of 2°C is quite significant considering the fact that for every degree C the temperature rises, the demand for electric power rises by 3% and the probability for a smog incident by 3% (LBNL Heat Island Group).

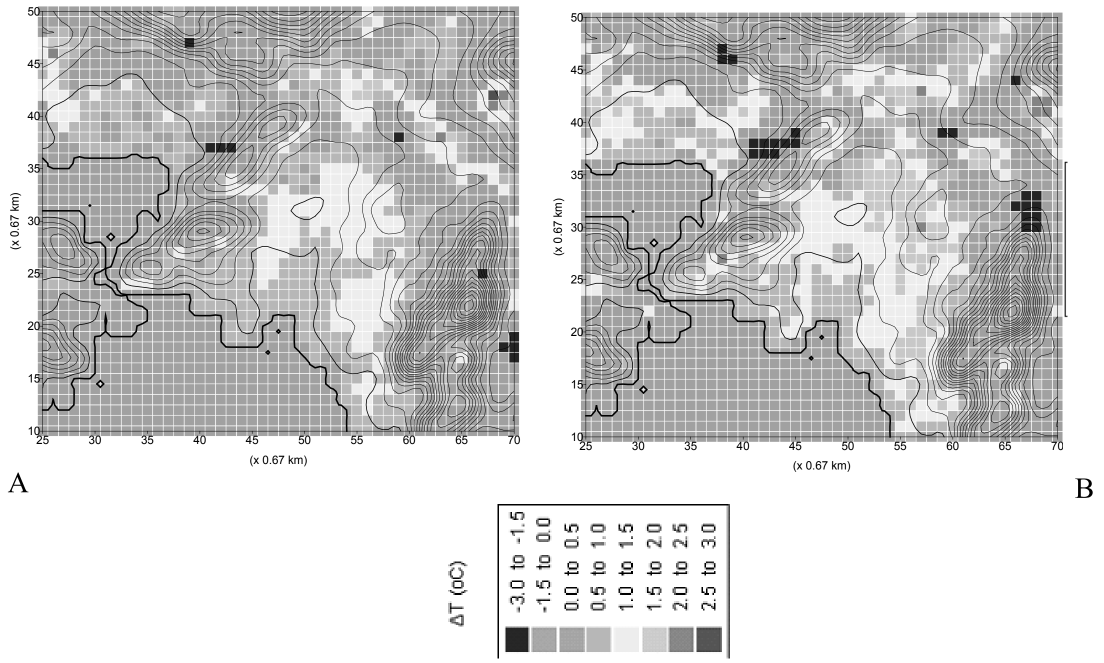

Figure 2: Air temperature differences between the base case and A) the moderate case scenario and B) the high increase in albedo scenario at 14:00 LST, on the 15th of August, 2005, with contour lines at 50 m intervals.

5 CONCLUSIONS

A simulation study was carried out aiming to assess the impact of using cool materials on roofs on the energy loads and indoor thermal comfort conditions in residential buildings for five cooling dominated cities. It was found that an increase in roof solar reflectance by 0.65 resulting from the application of a cool coating, reduces cooling loads by 21 to 48 kWh/m^2, and also the hours of discomfort and peak indoor temperatures by 2.7-3.3°C. Furthermore the possible impacts of large-scale increases in surface albedo on heat island mitigation were investigated using the mesoscale model MM5 (V3-6-1). Two cases of increased albedo have been simulated: a moderate one where the albedo of building structures is considered to be 0.63 and an extreme case with building structures' albedo equal to 0.85. It was demonstrated that for the first case air temperature can decrease by 1.5°C and for the second one by 2.2°C. The change in surface albedo can be achieved gradually if cool materials are chosen to replace dark existing ones during maintenance or in new structures. The use of cool materials is an inexpensive and passive solution that can contribute to increasing thermal comfort by lowering ambient temperatures and reducing energy demand for cooling. The results of this study can contribute to the promotion of the use of cool materials as well as the adoption of high albedo measures in building energy codes and urban planning regulations.

REFERENCES

H. Akbari, S. Bretz, D. Kurn, J. Hanford, Peak power and cooling energy savings of high-albedo roofs, Energy and Buildings 25 (1997) 117–126.

Akbari H., P. Berdahl, A. Desjarlais, N. Jenkins, R. Levinson, W. Miller, A. Rosenfeld, C. Scruton, S. Wiel, (2004) Cool colored materials for roofs, in: ACEEE Summer Study on Energy Efficiency in Buildings, Proceedings of American Council for an Energy Efficient Economy, Asilomar Conference Center in Pacific Grove, CA, August 2004.

Berdahl, P., Bretz, S.E., 1997. Preliminary survey of the solar reflectance of cool roofing materials. Energy and Buildings 25, 149–158.

Cartalis C., A. Synodinou, M. Proedrou and A. Tsangrasoulis and M. Santamouris, (2001). Modifications in energy demand in urban areas as a result of climate changes: An assessment for the southeast Mediterranean region, Energy Conversion and Management, 42 (14), 1647-1656.

Cheung C.K., Fuller R.J., Luther M.B., Energy efficient envelope design for high rise apartments, Energy and Buildings 37 (1) (2005) 37–48.

Dandou, A., Tombrou, M., Akylas, E., Soulakellis N., and Bossioli E.: 2005, 'Development and evaluation of an urban parameterization scheme in the Penn State/NCAR Mesoscale Model (MM5)', *J. Geophys. Res.* **110**, D10102, doi: 10.1029/2004JD005192

Fishman B., Taha H. and Akbari H., (1994). Mesoscale cooling effects of high albedo surfaces:Analysis of meteorological data from White Sands National Monument and White Sands Missile Range. LBL Report 35056.

Grell, G. A., Dudhia, J., and Stauffer D.: 1994. 'A description of the fifth-generation Penn state/NCAR mesoscale model (MM5)', *NCAR technical note*, NCAR/TN-398 +STR, National Centre for Atmospheric Sciences, Boulder , CO, 138 pp.

METEONORM, Global Meteorological Database for Solar Energy and Applied Climatology, Swiss Federal Institute of Technology, Zurich, Switzerland.

Miller W.A., Desjarlais A.O., Akbari H., Levinson R., Berdah, P., Scichili R.G., Special IR reflective pigments make a dark roof reflect almost like a white roof, in: Thermal Performance of the Exterior Envelopes of Buildings, IX, in Progress for Proceedings of ASHRAE THERM IX, Clearwater, FL, 2004.

Oke, T.R., D.G. Johnson, D.G. Steyn, and I.D. Watson, (1991): Simulation of surface urban heat island under 'ideal' conditions at night – Part 2 : Diagnosis and Causation. Bound. Layer Meteor., 56, 339-358.

Rosenfeld A.H., Akbari H., Pomerantz M., Taha H., Romm J.J., Policies to reduce heat islands: magnitudes of benefits and incentives to achieve them, in: Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings, vol. 9, 1996.

Santamouris, M.(Ed.) (2001). Energy and climate in the urban built environment. James and James Science Publishers, London.

Santamouris M (2006): Heat Island Research in Europe – The State of the Art. Journal Advances Building Energy Research, (Review Paper), Vol.1.

A. Shariah, B. Shalabi, A. Rousan, B. Tashtoush, Effects of absorptance of external surfaces on heating and cooling loads of residential buildings in Jordan, Energy Conversion and Management 39 (1998) 273–284.

Sailor, D., 1993: Role of surface characteristics in urban meteorology and air quality. Lawrence Berkeley National Laboratory Report No. 34459, UC-Berkeley, Doctoral Thesis.

J.R. Simpson, E.G. McPherson, The effects of roof albedo modification on cooling loads of scale model residences in Tucson Arizona, Energy and Buildings 25 (1997) 127–137.

TRNSYS (Version 15), A Transient System Simulator Program, Solar Energy Laboratory, University of Wisconsin, Madison, USA.

Stathopoulou M., Cartalis C. and Andritsos A., (2005) Assessing the thermal environment of major cities in Greece, Proceedings of the 1st International Conference on Passive and Low Energy Cooling for the Built Environment, Santorini, Greece.

Synnefa, A., Santamouris, M., Livada, I., 2006. A study of the thermal performance and of reflective coatings for the urban environment. Solar Energy 80, 968–981

Synnefa A., Santamouris M., Apostolakis K.(2007). On the development, optical properties and thermal performance of cool colored coatings for the urban environment. Solar Energy 81, 488-497.

Taha H. (1997). Modeling the impacts of large-scale albedo changes on ozone air quality in the South Coast Air Basin. Atmospheric Environment 31, No. 11, pp. 1667-1676.

Taha H., Konopacki S., Gabersek S., Impacts of large scale surface modifications on meteorological conditions and energy use: a 10-region modeling study, Theoretical and Applied Climatology 62 (1999) 175–185.

Taha H., Chang S., Akbari H. (2000). Meteorological and air impacts of heat island mitigations measures in three U.S. cities. LBNL report 44222.

Taha H., Hammer H.., Akbari H. (2002). Meteorological and air impacts of increased urban surface albedo and vegetative cover in the Greater Toronto Area, Canada. LBNL report 4921

Composite panels reinforced with waste fibrous materials

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ABSTRACT: The current work is concerned with the development of composite panels reinforced by waste fibrous materials. In this work, results of mechanical and physical properties, namely tensile and bending strength and percentage of water absorption, are presented and discussed. Four types of composite panels have been produced keeping constant the quantity of waste fibrous materials, type of resin and solvent used (in mass). Denim, carding, sisal and multifiber waste fibrous materials were used as reinforcement of a thermoset resin. A hydraulic heated press has been used to produce composite panels.

1 INTRODUCTION

Nowadays, the cost, quality and availability of raw materials are of paramount importance. Due to environmental concerns, a very large number of companies are currently developing manufacturing processes using alternative materials for their products and seeking new markets for the sub-products of their first-line production.

Textile industries are an example of the reality that the industry is living nowadays. With a significant production of waste fibrous material, textile industries are now looking for applications where waste fibrous materials could be an added-value(Woolridge et al, 2006). One viable application of these waste materials is in the combination with polymeric matrixes, producing composite materials with interesting properties for specific applications, from furniture to thermal and acoustic insulations.

Once most of these waste fibrous materials are based on natural fibers, the production of eco-composites can be a reality, especially when polymeric matrixes environmental friendly are used.

Composites reinforced by fibers are increasingly being considered for several uses when high performance is required (Moura, 2005). The corrosion resistance, potentially high overall durability, light weight, tailor ability and high specific performance attributes enable the use of composite materials in areas in which the use of conventional material might be constrained due to durability, weight or lack of design flexibility. Fiber reinforced polymeric matrix composite materials hitherto used predominantly in applications where high mechanical properties are requested, such as aerospace industry, aircraft and automobile materials, civil infrastructure materials, among others. However, the definition of high performance material is not only related to materials that present high mechanical behaviour, but also to material possessing any other high specific behaviour (Gomes et al, 2006). Therefore, any kind of material with high durability, extreme light weight or corrosion resistance higher than the conventional materials, for example, can be considered as a high performance material. Roof and wall panels, automobile interiors, storage devices, thermal and acoustic insulation material, furniture, and others, are few examples of applications where materials with specific high behaviour are required and the mechanical behaviour is not the most important property.

2 EXPERIMENTAL WORK

2.1 *Raw materials*

In order to produce composite panels for general use, namely thermal insulation, acoustic insulation or furniture panels, four different types of waste fibrous materials were used as reinforcement of a thermosetting resin.

The waste fibrous materials used in this work were:

- Sisal Fiber Waste: natural fibers with diameters between 125 and 500µm and lengths between 1-3cm;
- Carding Fiber Waste: textile waste fibers, resulting of the carding process;
- Denim Fiber Waste: 95% cotton fibers approximately;
- Multi-fiber Waste (mixed fibers): different textile waste fibers with unknown composition.

The composite panels were produced with a combination of waste fibrous materials and a thermosetting resin (urea-melamine) dispersed in a water base with different resin contents. In order to evaluate the influence of waste fiber type and the influence of resin content, several composite panels were produced as presented in Table 1.

The waste fibrous materials were supplied by textile companies running in the North of Portugal.

Table 1. Resin and fiber waste content of the panels produced.

Resin content [%]	Waste fibrous material content [%]
10.0	90.0
12.5	87.5
15.0	85.0
20.0	80.0

2.2 *Composite panels production method*

The waste fibrous materials were mixed in a kinetic mixer with the thermoset resin. The final mixture was then placed in a hydraulic heated press, subjected to temperature and pressure. After then, the material was subjected to a decompressing process. Thus, waste fibrous materials composite panels were produced with the dimensions of 500×500mm length/width and thickness between 5 and 17mm. Figure 1 presents some of the composite panels produced according to this production procedure.

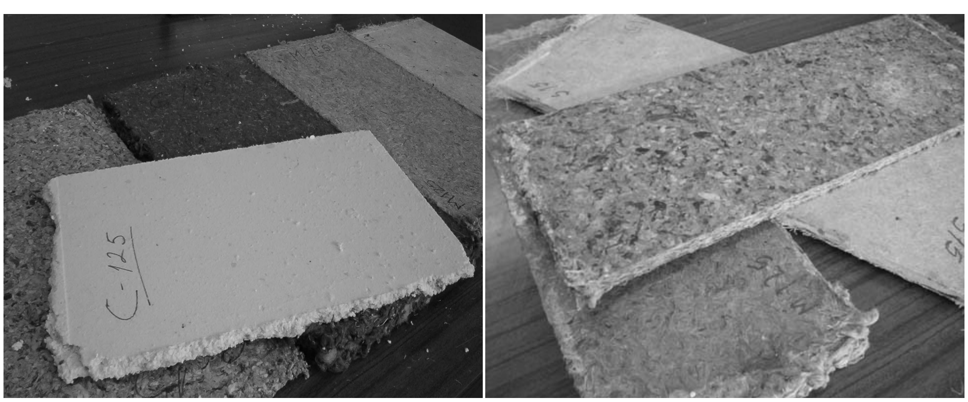

Figure 1. Waste fibrous material composite panel.

For each resin content several production parameters were maintained constant, namely:

- Temperature – 130ºC
- Pressure – 30bar
- Production cycle – compressing (5min) - decompressing (2 min)
- Panels dimensions – 500mm length and 500mm width
- Dry waste fibrous material quantity
- Dry resin quantity.

Due to the specific behaviour of the different waste fibrous materials and due to the maintenance of the above parameters, composite panels with different thicknesses were obtained.

2.3 *Waste fibrous materials composite panels and their characterization*

Sixteen different composite panels were produced with 4 types of waste fibrous materials and four different resin contents.

Composite panels basic characterization was carried out, namely the determination of the panels' geometry (Figure 2) and their density (Figure 3).

Composite panels with 10% of resin content presented thickness values between 4 and 4.8mm. 12.5% resin content composite panels presented a thickness between 11 and 15.5mm. The thickness of composite panels with 15% and 20% of resin content were from 12.5 to 18mm and 11 to 14mm, namely (Figure 2).

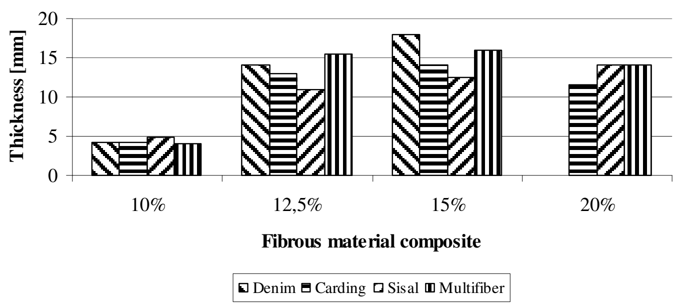

Figure 2. Waste fibrous material composite panel thickness.

Composite panels with 10% of resin content presented densities from 736 to 967 kg/m^3. 12.5% resin content composite panels presented density values between 502 and 737 kg/m^3. The densities of composite panels with 15% were of 464 to 633 kg/m^3. 20% resin content composite panels presented densities from 604 to 716 kg/m^3 (Figure 3).

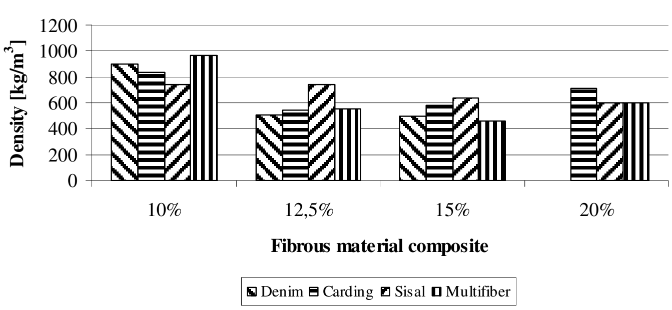

Figure 3. Waste fibrous material composite panel density.

Mechanical evaluation was carried out in the composite panels by the analysis of the tensile and bending behavior (Figure 4-6).

Density is an intrinsic property of any material and influences its mechanical and physical properties. In order to allow the comparison between different panels, with different densities, the tensile strength, bending strength and bending modulus were divided by the panels' density. Thus, the results obtained are comparable once they are function of kg/m^3.

Tensile tests were carried out according to the standards ASTM D5035 and EN319. Figure 4 presents the tensile strength results obtained, taking into account the materials density. 10% resin content composite panels presented tensile strength/density ratios between 5.17×10^{-5} and 4.93×10^{-4} MPa/(kg/m^3). 12.5% resin content composite panels presented tensile strength/density ratios values between 3.61×10^{-5} and 7.97×10^{-4} MPa/(kg/m^3). The tensile strength/density ratio values of composite panels with 15% are from 2.16×10^{-5} to 1.42×10^{-4} MPa/(kg/m^3). 20% resin content composite panels presented tensile strength/density ratio values from 1.12×10^{-4} to 3.15×10^{-4} MPa/(kg/m^3) (Figure 4).

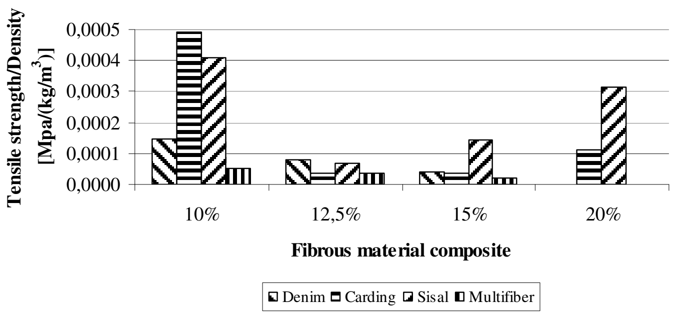

Figure 4. Waste fibrous material composite panel tensile strength comparison.

Bending test was carried out according to the standard EN 310. As can be seen in Figure 5, 10% resin content composite panels presented bending strength/density ratios between 2.21×10^{-3} and 7.69×10^{-3} MPa/(kg/m^3). 12.5% resin content composite panels presented bending strength/density ratios values between 4.70×10^{-3} and 1.74×10^{-2} MPa/(kg/m^3). The bending strength/density ratio values of composite panels with 15% are from 2.99×10^{-3} to 2.41×10^{-2} MPa/(kg/m^3). 20% resin content composite panels presented bending strength/density ratio values from 8.73×10^{-3} to 3.05×10^{-2} MPa/(kg/m^3).

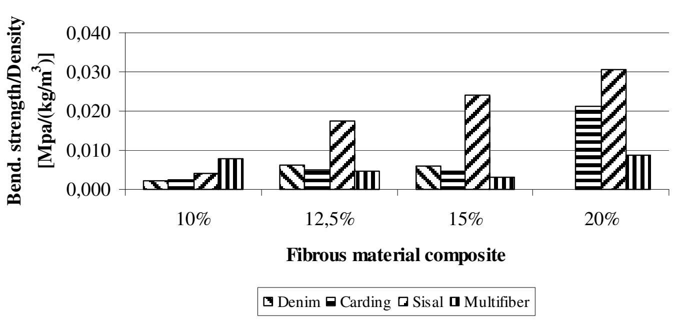

Figure 5. Waste fibrous material composite panel bending strength comparison.

Figure 6 shows the bending modulus/density ratio of the different panels produced. 10% resin content composite panels presented bending modulus/density ratios between 4.12×10^{-1} and 7.70×10^{-1} MPa/(kg/m^3). 12.5% resin content composite panels presented bending modulus/density ratios values between 4.86×10^{-1} and 1.20 MPa/(kg/m^3). The bending modulus/density ratio values of composite panels with 15% are from 2.84×10^{-1} to 1.49 MPa/(kg/m^3). 20% resin content composite panels presented bending modulus/density ratio values from 5.33×10^{-1} to 5.19 MPa/(kg/m^3).

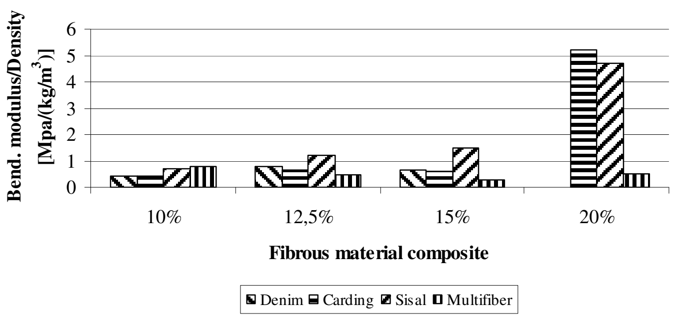

Figure 6. Waste fibrous material composite panel bending modulus comparison.

Water absorption and volume increase due to water absorption were determined in order to evaluate the physical properties of the composite materials (Figure 7-8), according to the standard EN 317. Once again, each parameter was divided by the material density in order to allow the comparison between the composite panels.

As can be seen in Figure 7, 10% resin content composite panels presented water absorption/density ratios between 6.02×10^{-2} and 1.16×10^{-1} %/(kg/m^3). 12.5% resin content composite panels presented water absorption/density ratios values between 1.12×10^{-1} and 3.52×10^{-1} %/(kg/m^3). The water absorption/density ratio values of composite panels with 15% were from 1.06×10^{-1} to 4.69×10^{-1} %/(kg/m^3). 20% resin content composite panels presented water absorption/density ratio values from 6.65×10^{-2} to 2.21×10^{-1} %/(kg/m^3).

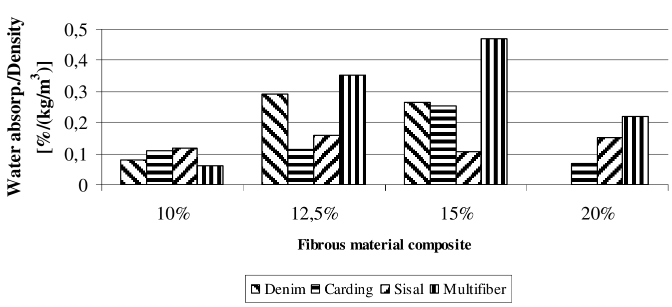

Figure 7. Waste fibrous material composite panel water absorption comparison.

The volume increase due to water absorption comparison can be seen in Figure 8. Composite panels with 10% resin content presented volume increase/density ratios between 1.25×10^{-2} and 3.80×10^{-2} %/(kg/m^3). 12.5% resin content composite panels presented volume increase/density ratios values between 2.20×10^{-2} and 7.39×10^{-2} %/(kg/m^3). The volume increase/density ratio values of composite panels with 15% were from 12.55×10^{-2} to 6.33×10^{-2} %/(kg/m^3). 20% resin content composite panels presented volume increase/density ratio values from 3.56×10^{-2} to 4.52×10^{-2} %/(kg/m^3) (Figure 8).

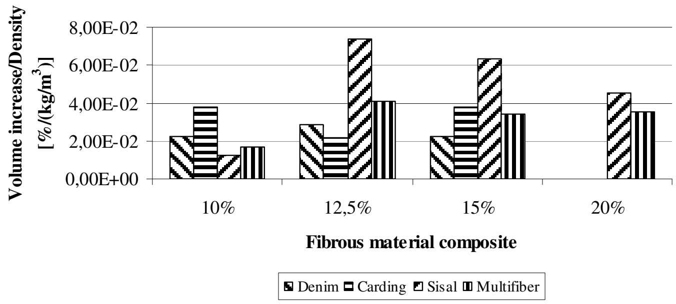

Figure 8. Waste fibrous material composite panel volume increase due to water absorption comparison.

2.4 *Waste fibrous materials composite panels result analysis*

The composite panels produced with 10% of resin content present the lowest thickness values and the highest density (Figure 1-2). 12.5%, 15% and 20% resin content composite panels present thicknesses and densities of the same range.

Analyzing the composite panels tensile behavior (Figure 3), the 10% resin content composite panel reinforced with multifiber fibers presented the highest tensile strength/density ratio. The 15% resin content composite panel reinforced with multifiber fibers presented the lowest tensile strength/density ratio.

In what concerns the bending behavior (Figure 5-6), composite panels reinforced with sisal presented the highest bending strength/density ratio and bending modulus/density ratio, for panels with 12.5% and 15% of resin content. In 10% resin content panels, the highest ratios were obtained using waste multifiber fibers. Significantly higher values were obtained in 20% resin content panels reinforced with carding and sisal waste fibers.

Multifiber composite panel with 15% of resin content presented the highest water absorption/density ratio although it had presented the lowest value when 10% of resin is used.

Sisal composite panel with 12.5% of resin content presented the highest volume increase due to water absorption/density ratio although it had presented the lowest value when 10% of resin was used.

Bending behavior follows the trend of tensile behavior for composite panels with 12.5% and 15% of resin content. Water absorption behavior follows the trend of tensile behavior for composite panels with 10% and 20% of resin content, except for carding composite panels.

3 CONCLUSIONS

Several composite panels were produced with different types of waste fibrous materials, denim, carding, sisal and multifiber, and urea-melamine polymeric matrix. In order to evaluate the influence of the type of waste fibrous materials and resin content used, mechanical and physical tests were carried out in the fifteen composite panels produced. Tensile and bending tests and water absorption and percentage of volume increased due to water absorption, besides the basic characterization of the composite panels, namely dimension and density, were carried out.

When subjected to bending, sisal composite panels presented the best behavior, except for 10% resin content panels. Denim and carding composite panels presented similar behavior to bending while multi-fiber composite panels presented the worst behavior of all.

Sisal composite panels presented the best tensile behavior, except for 10% resin content panels. Multi-fiber panels presented the lowest tensile strength/density ratio.

Composite panels reinforced with multifiber fibers present the highest water absorption, except for 10% resin content panels.

The highest volume increased by the water absorption was from sisal composite panels for resin contents higher than 10%.

One can conclude that trends between the mechanical and physical properties are not clear to identify.

Further research work is being undertaken in order to overcome the problems encountered in this work, namely the difficulty in finding the mechanical and physical pattern behavior of the panels.

The production techniques are being improved and the hydraulic press conditions are being reviewed.

4 ACKOWLEGMENTS

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REFERENCES

ASTM D5035 - Test Method for Breaking Strength and Elongation of Textile Fabrics (Strip Method)

Conroy, A., Halliwell, S., Reynolds, T. Composite recycling in the construction industry. Composites, Part A, XX; 2005, p. 1-7.

EN 310 - Wood-based panels - Determination of modulus of elasticity in bending and of bending strength

EN 317 - Particleboards and fiberboards - Determination of swelling in thickness after immersion in water

EN 319 - Particleboards and fiberboards - Determination of tensile strength perpendicular to the plane of the board

Gomes, M. G., Fangueiro, R., Gonilho Pereira, C. Composite materials reinforced by waste fibers, 5th International Conference on Mechanics and Materials in design, 24-26 July, 2006, Porto, Portugal

Moura, Marcelo F.S.F., Morais, Alfredo B., Magalhães, António G. Materiais Compósitos – Materiais, Fabrico e Comportamento Mecânico, 2005, p.15-21

Woolridge, Anne C., Ward, Garth D., Phillips, Paul S., Collins M., Gandy S. Life cycle assessment for reuse/recycling of donated waste textiles compared to use of virgin material: An UK energy saving perspective. Resources, Conservation and Recycling, 46; 2006, p. 94-103.

Using mine waste mud to produce environmentally friendly new binders

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ABSTRACT: It is now accepted that new binders, such as alkali-activated binders, are needed to replace portland cement for enhanced environmental and durability performance. Alkali-activated binders have emerged as an alternative to (ordinary portland cement) OPC binders, which seem to have superior durability and environmental impact.This paper reports results of a research project on the development of an alkali-activated binders using mineral waste mud from the Panasqueira tungsten mine in Portugal. Results show that with proper mix design, this new binder presents exceptionally high compressive strength even at early ages. Results also indicate, better abrasion and acid resistance compared with concrete using OPC. Leaching tests show that the new binder is considered an inert material which indicates that it could be used as a building material.

1 INTRODUCTION

Alkali-activated binders have a long history in the former Soviet Union, Scandinavia, and Eastern Europe (Roy, 1999). In 1978, Davidovits coined the term "geopolymer", to describe new materials with the ability to transform, polycondense and adopt a shape rapidly at low temperatures like "polymers" (Davidovits,1991).

The polymerisation process involves a chemical reaction under higly alkaline conditions in which Al-Si minerals yield polymeric Si-O-Al-O bonds with an empirical formula Mn [- (Si - O_2)z – Al - O]n. wH2O, where n is the degree of polymerization, z is 1, 2 or 3, and M is an alkali cation, such as potassium or sodium (Davidovits, 1999). Davidovits reported several advantages of geopolymeric cementitious systems over Portland cement mainly environmental, due to the fact that geopolymeric based concrete has a much longer service life than Portland cement based ones, high capacity for heavy metals waste encapsulation and to lower CO_2 emissions, 0,18 tonnes of CO_2 per tonne of cement (Davidovits, 2002).

The geopolymerisation requires a precursor that contains significant quantities of silicon and aluminium in an amorphous phase such as fly ashes from electrical power stations. Portuguese generation of fly ash is near 3% of the annual Portuguese Portland cement production. This means that aluminosilicates from geologic origin are probably the only reasonable alternative material for production of alkali activated environmental friendly binders.

Previous studies concerning the geopolymerization of different minerals suggest that a wide range of Al-Si based minerals can be used as sources of precursors (Xu & Deventer, 2000). However it must be noted that they used highly pure geological specimens. This research work deals with the use of mine waste minerals that are expected to behave differently.

2 THE RESEARCH

2.1 *Mine waste raw material*

Panasqueira is an underground mine utilizing room and pillar mining methods situated in central Portugal on the southern edge of the Sierra da Estrela mountain range, a natural park, close to Serra do Açor, a protected landscape, and also near the Zezere river (Fig. 1).

Figure1. Aerial View of the Panasqueira tungsten mine

Tungsten and tin have been mined in the Panasqueira area since the 1890s. In the mid 1980s, Panasqueira's had over 1,000 employees in its underground mining and plant operations that processed 600 000 tonnes of ore per annum to produce in excess of 2,000 tonnes of tungsten oxide (WO_3) representing 0,3 % of excavated rock. During the mining process two types of mine waste are generated, coarse aggregates derived from rock blasting which is in fact a by-product used in minor quantities by the road pavement industry and waste mud conveyed by pipelines into lagoons amounting to a several million tonnes of deposited material, while still generating almost 100 ton per day.

Tungsten mine waste mud used in this study was subjected to a thermal treatment at 950º C during 2 hours, mineralogical composition and thermal conditions are described elsewhere (Torgal, 2007).The XRD patterns indicated that mine waste mud consists mainly of muscovite and quartz which were identified by their characteristic patterns as follows: muscovite (card 46 - 1409) and quartz (card 46 - 1045). For wastes treated under these thermal conditions XRD patterns indicated that dehydroxylation did not result in a complete collapse of muscovite structure. Calcinations leads to formation of an amorphous phase, causing an increase in the general background (BG) of XRD patterns that predominantly take place in the interval of 850 ºC to 950º C. This thermal behaviour is similar to that of other phyllosilicate clay minerals (He et al., 2005). The main muscovite peak (2θ=8,8º) persisted even after the sample had been heated at 950 ºC although it decreased considerably. Peak area measurements revealed that about 12% of muscovite survived calcination at 950 ºC.

Molecular changes during dehydroxylation were also examined with infrared emission spectra (FTIR), confirming decrease in the absorption peaks at 3600-3700 (OH stretch), however the main muscovite peak did not disappear totally indicating only a partial transformation. Compressive strength data related to geopolymeric mortars made using raw waste mud and calcined waste mud showed an increase of more than 300%, hence, justifying the thermal treatment.

Calcinations of mine waste mud in a static furnace, as the one used in this study, need large amounts and may become expensive and less environmental friendly. However, industrial flash calciner have been already developed with 800 Kg/h production units, capable of reduction calcination time to a few seconds and with the additional advantage of dispensing with the further grinding operations (Salvador, 2000). This process apparently cuts down significantly the cost of thermal treatment.

2.2 *Chemical composition and specific surface*

The chemical composition and specific surface of the mine waste mud are shown in Table 1.

Table 1.Chemical composition and specific surface

Constituents (%)	Mine waste mud
SiO_2	53,48
$Al_2 O_3$	16,66
$Fe_2 O_3$	12,33
$K_2 O$	7,65
$Na_2 O$	0,62
Mg O	1,27
$S O_4$	3,10
$Ti O_2$	1,39
As	1,28
Other minor oxides	2,22
Blaine fineness (m^2/kg)	357

The figures clearly show that mine waste mud consists essentially of silica and alumina, contaminated with arsenic and sulfur and with a high content of iron and potassium oxide content. Although it is known that iron oxide contributes to the strength gain of Portland cement its contribution in geopolymer cement is still not well understood. The SiO_2/Al_2O_3 atomic ratio is 5,5 higher ~2 suggested by Davidovits for making cement and concrete. However, Pinto (2004) using alkali-activated metakaolin based mixtures found that some mixtures with calcium hydroxide and an atomic ratio of SiO_2/Al_2O_3= 5,1 lead to higher compressive strength gains. Nonetheless, the final SiO_2/Al_2O_3 atomic ratio in the hardened binder depends mainly on the reactivity of Al-Si because not all the silica and alumina are reactive. In spite of the fact that Al and Si have synchro-dissolution behaviour in alkaline solution, e.g they dissolve from the mineral in some linked form; one can not expect the same Si/Al ratio in the final hydration product as the one present in the original precursor material. Indeed most of the Al-Si materials cannot even supply sufficient Si in alkaline solution to start geopolymerization, this explains why they need extra silica provided in solution by waterglass, which influences the Si/Al ratio of the hardened binder.

The Blaine fineness of the mine waste is relatively low, but is still in the range of the most used slag based alkaline binders. To compensate for this lack of high fineness, higly alkaline-silicate activators can be used. Some authors analyzed the joint effect of specific surface, curing temperature, nature and concentration of alkaline activator and found out that specific surface is the factor statistically least relevant. In some cases, a decrease in mechanical properties with increase in specific surface has been reported when NaOH and waterglass activator has been used (Fernandez-Jimenez et al., 1999).

2.3 *Mix design*

Given the proper mix design geopolymeric mine waste mud (GMWM) binders shows significant early age cementing properties. The H_2O/ Na_2O molar ratio in the mixture is an important parameter being closely related to compressive strength and structure formation. This can be attributed to increased dissolution of mine waste in the presence of sodium hydroxide at higher concentrations. The use of waterglass/sodium hydroxide mass ratios of 2:1 and 1,5:1 and high levels of calcium hydroxide content and sodium hydroxide concentration leads to unfeasible mixtures due to a very fast setting time and hardening rate. Early age compressive strength of alkali-activated MWM mortars is highly dependent on the calcium hydroxide content. The use of alkali-activated MWM mortars with a waterglass/sodium hydroxide mass ratio of 2,5:1 and a calcium hydroxide content of 10% leads to the highest early age strength resulting in 31 MPa for 7 days curing (Torgal et al., 2006). The strength data for long curing ages, show that the parameters which lead to optimum strength for 7 days curing remain the same for long curing times. However, when calcium hydroxide percentages above 10% are used, a relevant strength decrease after 14th curing day is noticed. The use of an activator with a sodium hydroxide concentration of 24 M leads to very high compressive strengths, for early ages with 30 MPa after just 1 day and 70 MPa for 28 days curing (Torgal et al., 2007). The highest compressive strength is obtained with a mixture containing 10% calcium hydroxide. The strength performance is typical of a very reactive binder, presumably due to the presence of calcium hydroxide and also to the nucleation centers provide by the iron oxide of the mine waste mud.

2.4 *Durability*

For the durability performance, abrasion and acid resistance were assessed for GMWM and comparable OPC binders. GMWM binder specimens show a low level of weight loss while in OPC specimens a severe weight loss is observed (Fig. 1). GMWM binder specimens show a low level of weight loss while in OPC specimens a severe weight loss was observed. For GMWM binders the higher abrasion resistance was achieved in paste specimens. This result is related to the fact that GMWM paste had the highest compressive strength. As for OPC specimens, abrasion resistance seems to be more influenced by the compressive strength than for the aggregates used in the mix.

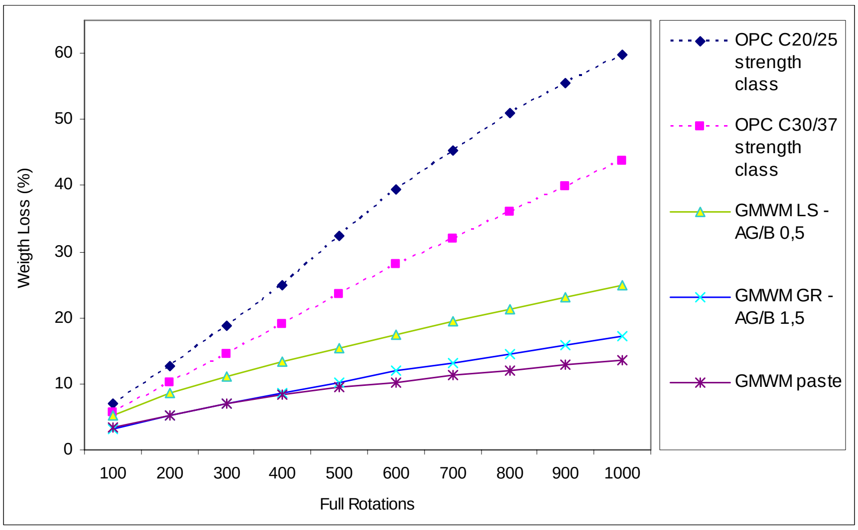

Figure 1. Abrasion resistance with the Los Angeles test, using 50mm cubic specimens of OPC and GMWM binders

As for acid resistance results are dependent not only on the type of acid but also on the type of aggregate used. For GMWM binders, the mixtures with granitic and schist aggregates showed low weight loss results when exposed to different acids. As for the mixtures with limestone aggregates their weight loss showed to be influenced by the type of acid. Specimens immersed in chloridric acid showed low weight loss performance independent of aggregate type, as for specimens submitted to nitric and sulphuric acid attack are influenced by the presence of limestone aggregates. GMWM binders without limestone aggregates show good acid resistance better than the OPC concrete. This behavior may be due to the low water absorption and to their low content in calcium.

2.5 *Environmental assesment*

The use of new binder as a building material requires the assessment of its environmental performance. For that leaching tests have been carried out according to DIN 38414 – S4. Leaching results show that all chemical parameters are below the limits established by the standard and can be considered an inert material (Table 2). As to the limits for water contamination set by the Decree 236/98, it can be stated that although some chemical parameters are above the limits for drinkable, all limits are met concerning water for irrigation purposes.

Table 2. Contaminant concentration in the wastewater by leaching process standard DIN 38414 – S4

Contaminant	Test results (mg/l)	Limits (DIN 38414 – S4)	
		Max.	Min.
Zinc	0,011	2	5
Arsenic	< 0,002	0,1	0,5
Lead	0,197	0,5	1,0
Copper	0,062	2	5
Manganese	0,019	-	-
Iron	0,203	-	-
Potassium	123,75	-	-
Sodium	3792,5	-	-
Magnesium	0,163	-	-
Sulphates	< 0,003	500	1500

3 CONCLUSIONS

The calcination of mine waste mud at 950 ºC during 2 hours leads to an increase of more than 300% in the compressive strength of alkali-activated mortars, thus justifying its thermal treatment.

The use of alkali-activated GMWM mortars with a waterglass/sodium hydroxide mass ratio of 2,5:1, with a sodium hydroxide concentration of 24 M and a calcium hydroxide content of 10% leads to the highest strength, indicating a 30 MPa after one day curing and 70MPa after 28 days curing.

Abrasion resistance of GMWM binders is higher than that of the current OPC binders. GMWM binders without limestone aggregates show good acid resistance, much higher than the one presented by OPC concrete. It is believed that this performance is due to the fact that the new binders have low water absorption and also to their low calcium content resulting in less soluble compounds.

As for the environmental assessment, the new binder is considered an inert material which indicates that it could be used as a building material.

REFERENCES

Davidovits, J., Geopolymers: Inorganic polymeric new materials. Journal of Thermal Analysis 37 (1991) 1633-1656.

Davidovits, J., Chemistry of geopolymeric systems, Terminology. Proceedings of Geopolymer 1999 International Conference. France

Davidovits, J., Environmentally driven geopolymer cement applications. Proceedings of 2002 Geopolymer Conference. Melbourne. Australia.

Fernandez-Jimenez, A.;Palomo, J.; Puertas, F., Álcali-activated slag mortars. Mechanical strength behaviour. Cement and Concrete Research 29 (1999) 1313-1321.

He, Changling; Makovic, Emil; Osbaeck, Bjame – Thermal stability and pozzolanic activity of raw and calcined illite. Applied Clay Science 9 (1995) 337-354

Roy, Della M., Alkali – activated cements. Opportunities and challenges. Cement and Concrete Research 29 (1999) 249-254.

Salvador, S. - A semi-mobile flash dryer/calciner unit manufacture pozzolana from raw clay soils - application to soil stabilization. Construction and Building Materials 14 (2000) 109-117.

Pinto, A. T. Metakaolin alkali-activated based binders. PhD Thesis, 2004, University of Minho. Portugal. [in Portuguese]

Xu, Hua; Deventer, J. S. J., The geopolymerisation of alumino-silicate minerals. International Journal of Mineral Processing 59 (2000) 247-266.

Torgal, F. M. Alves S. P. Development of alkali-activated binders using waste mud from Panasqueira mine. PhD Thesis, 2007. University of Beira Interior [in Portuguese]

Torgal, F. M. Alves S. P.;Castro Gomes, J. P.;Jalali, Said., Investigations on mix design of tungsten mine waste geopolymeric binder. Construction and Building Materials. (in press, 2007)

Torgal, F. M. Alves S. P.;Castro Gomes, J. P.; Jalali, Said., Investigation about the effect of aggregatees on strength and microstructure of tungsten mine waste mud geopolymeric binders. Cement and Concrete Research. (in press, 2007)

Wang, Shao-Dong; Scrivener, Karen; Pratt, P., Factors affecting the strength of alkali-activated slag. Cement and Concret Research 24 (1994) 1033-1043.

Zivica, V.; Bazja, Adolf; Acid attack of cement based materials – a review. Part 1. Principle of acid at tack. Cement and Concrete Research 15 (2001) 331-340.

Use of cellulose sludge in the production of fibrocement building materials

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ABSTRACT: Pulp and paper industrial sector generates annually a large amount of residues. One of the major wastes is the sludge from the effluents primary treatment (PTS - primary treatment sludge). An attempt is made to substitute traditionally used celluloses long fibres by PTS (short fibres) in the fibrocement manufacture.
Aiming the identification of an optimal amount, the behaviour of the fibrocement composite was studied in function of the substitution content. Replacement amounts up to 100% were processed and relevant processing parameters like density, solids in suspension and mechanical strength were measured.
Substitutions between 20 to 50% induce a good value of particles retention compared to the reference one. Furthermore, negligible reduction in strength (~1-2 MPa) for those substitution levels was verified. These fibrocement product features, important for processing and application, are not hindered by the incorporation of wastes.

1 INTRODUCTION

Paper or pulp industry produces large volumes of waste sludges, primarily as a result of processes as de-inking wastepaper and waste water treatment. These sludges represent approximately two thirds of the total solid wastes from a paper pulp mill [Podobnik et al., (2006)]. Based on the need to add value to these wastes, this study tries to evaluate the substitution of the traditionally used cellulose fibre (long fibre) by the effluent primary sludge treatment. The fibrocement material with cellulose fibres have been used in many countries, particularly after the legal obligation of replacing asbestos [Coutts & Ni (1995)]. Cellulose fibres are an interesting contribute to reinforce the cement matrix due to its low cost, availability and energy economy [Anjos et al. (2003)]. This sector annually sends for landfill deposition thousands of tons of wastes. Most of these wastes present a great potential of reuse, namely the sludges from the primary treatment effluents (PTS).

As an attempt to add value to these wastes, the production of fibrocement was considered because, traditionally, cellulose fibres (long fibre) are used in its formulation but also because it is a high tonnage production and compatibility at this level is important. The impact that may arise from this replacement corresponds to alterations of formed structures due to the different ratios and dimensions of the fibres. The long fibre, of bigger length and wall thickness, allows a bigger number of inter-fibre links allowing structures with higher mechanical strength. However, high levels of the beating process can promote its cut, affecting the tensile strength of this type of structures when compared with the eucalyptus fibres. On the other hand, if the long fibres are exposed to less beating they constitute less dense structures, as resulted from their superior dimensions. These results may improve with the beating of both types of fibres due to a intertwining process between them.

This waste valorisation solution is highly recommended since it can solve at the same time the problem of two industrial sectors giving a true meaning to a sustainable action. As a matter of fact, wastes are deviated from going to landfill deposition or occasional agriculture applications and are introduced as a raw material, preventing natural resources consumption.

In this work, the alteration of formed structure with the use of different ratios of this type of fibres was evaluated taking into account some fundamental properties of the modified samples. This is also important to set up the industrial production tests that are indispensable to accept the solution as viable for the future.

2 EXPERIMENTAL

2.1 *Materials processing*

Samples of fibrocement were firstly produced in the Laboratory to evaluate several replacement contents of the traditionally used commercial long fibre by the short eucalyptus fibre present in the primary treatment sludge (PTS).

For each replacement amount six samples were made and tested (figure 1). The sample with the commercial composition (without sludge) was named as the reference sample (Ref). The other samples include different amounts of PTS in substitution of the traditional long fibre. These replacement amounts were 10, 20, 30, 50 and 100% of PTS.

The processing involves first, for each batch, the preparation of a suspension in distilled water with all the components in the formulation. After stirring for one minute and a half, the suspension is filtrated trough a sieve with similar dimensions as the one used in the regular process. This filtration is performed with the assistance of a vacuum pump and, at the end, the sample is submitted to a compaction with a rolling disk. The solid sample is then retrieved and weigh still wet. At this stage, final pressing operation is engaged using an applied pressure of 10 MPa for 5 seconds. Then, the pressed sample is again weighed and its thickness measured.

The last step of sample preparation is the curing procedure since it is a cement-based material. Curing in this type of materials involves a conditioning period at 22ºC in a water-saturated environment (immersion). Samples were cured for 7 days and then characterized.

Figure1. Set of fibrocement samples.

2.2 *Characterization tests*

Samples were characterized in terms of density, total solids in suspension and mechanical strength, due to their particular importance as evaluation parameters for future industrial tests and because they are considered important as final product characteristics.

Density of the samples was measured by the liquid immersion technique. Determination of total solids in suspension was performed in the filtered suspension with a standard method [Standard method (1998)]. This test also gives information on the ability for fine particles retention by the fibrocement product. This information is very important in terms of production efficiency.

Mechanical strength was determined by the three-point bending mode (figure 2) yielding the flexural strength of the material.

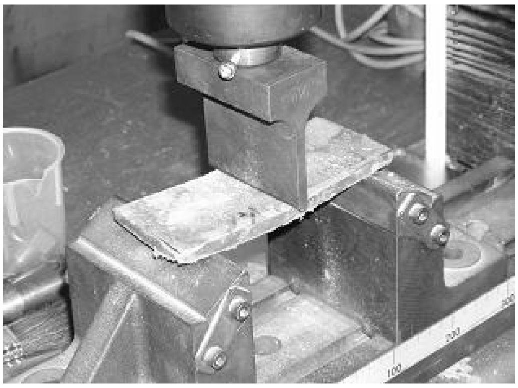

Figure 2. Flexural mechanical strength test.

3 RESULTS AND DISCUSSION

Figure 3 shows that the incorporation of primary treatment sludge (PTS) in the fibrocement formulation did not altered the density of the samples (~1.5-1.6), as expected since it is just a replacement of the same kind of fibrous material (a cellulose based one). Indeed, fluctuations are well inside the variations limits of the experimental determinations.

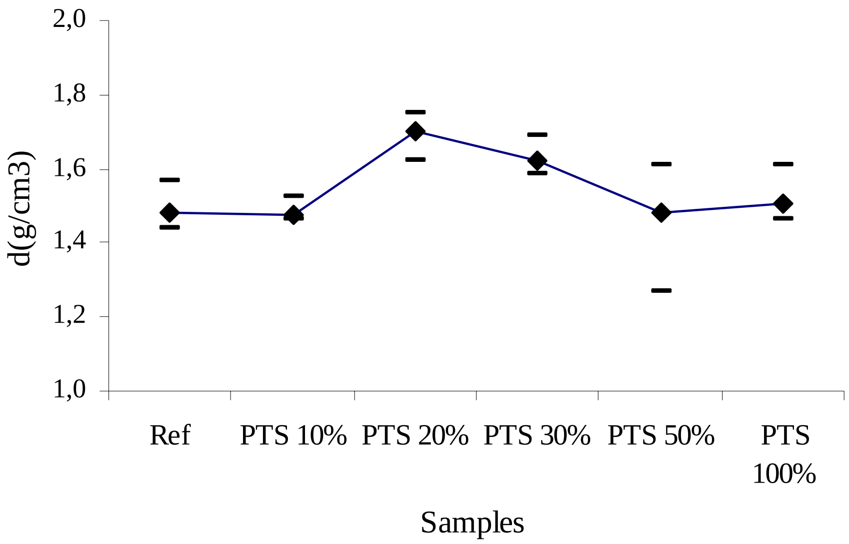

Figure 3. Density variation with the content of wastes (PTS) in fibrocement.

Figure 4 presents the results on the ability of the fibrocement to retain the finer particles, one of the most important processing parameters. This ability is important, during the process of building up the fibrocement layers until the final structure, because it allows retaining the fine cement particles that act as binder, assuring the necessary cohesion of this composite. An excessive retention is also not advisable since it hinders the product drain ability making it too impervious.

The total solids in suspension are taken from the weight loss of the filtered material. This determination gives an indication of the fine particle retention by the product. A high weight loss value means a low retention ability which is a bad indicator for production because a lot of material can be lost in this step. Hence, the weight loss should be kept low. Indeed, as one can observe in figure 4, the replacement of the traditional long fibre by the PTS waste also caused a small variation in this parameter, keeping it below 5%, even for higher substitution levels.

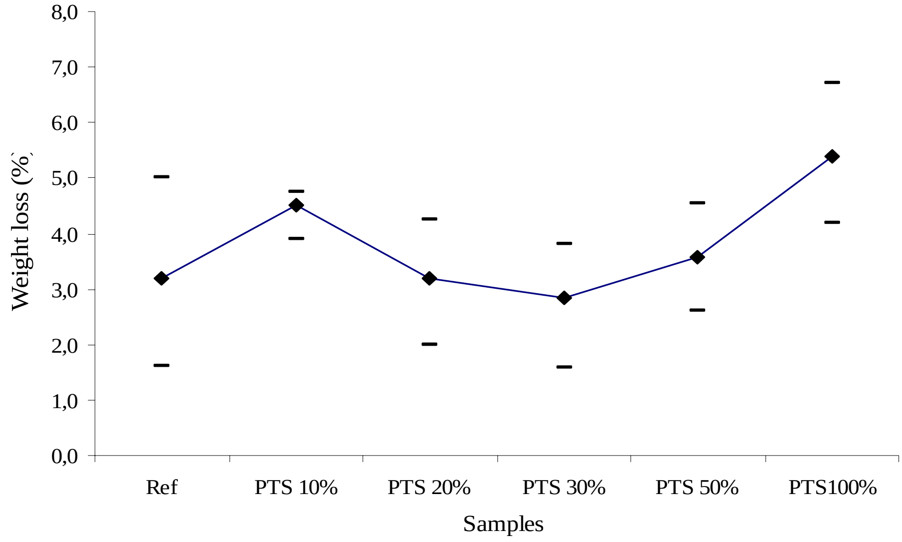

Figure 4. Fine particle retention ability as a function of wastes (PTS) incorporation.

This small relative change compared with the reference sample (Ref) hides an interesting phenomenon. Compared with its replacement target, the used PTS from the paper pulp plant contains typically higher amounts of finer inorganic filler (precipitated calcium carbonate) that can ascend up to 30%. This fact increases the PTS potential weight loss, hence, more material susceptible to be filtered away to the suspension. Even so, the measured value is not higher than the reference sample, which can only indicate that the mixture between fibres of different dimensions (long and short) can lead to an effective intertwining/bridging process which, in turn, contributes to a higher retention value. As a matter of fact, this phenomenon has already been used by the paper industry to engineer their product, employing this type of mixing in order to reach compromises on the paper final characteristics regarding their specific application.

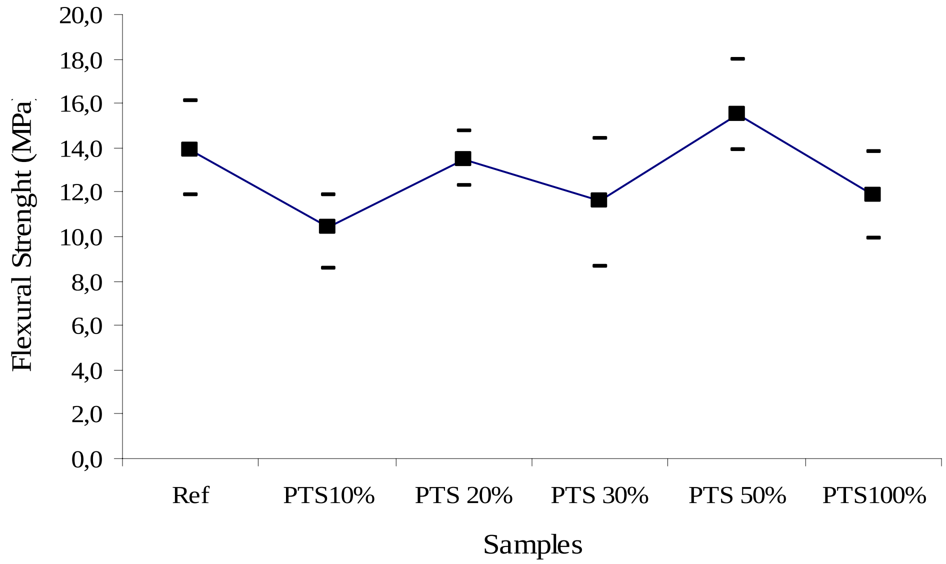

Figure 5. Flexural mechanical strength variation with the amount of incorporated wastes (PTS).

Figure 5 presents one of the most critical parameters in terms of real application, the flexural mechanical strength. It is possible to verify that the waste incorporation (PTS) into the fibro-cement formulation allowed keeping the mechanical strength. The observed variations are well inside the experimental variation limits which confirm the viability of this kind of solution to add value to an industrial waste and save resources in the production of a building material. The variability of the measured features is not very high and accompanies well, without distorting, the trend of the average values.

Looking in detail to the variations of these three measured parameters, one could say that for substitution levels up to 50% PTS, variations are negligible and it seems to be technically viable and promising the realization of large scale industrial tests. In those, one must test other processing characteristics, such as the fibre refinement conditions, in order to promote a good incorporation of the maximum amount possible of this waste (PTS).

4 CONCLUSIONS

Fibrocement products were obtained incorporating primary treatment sludges from paper pulp plants. All range (0-100%) substitution was attempted and guaranteed since no dramatic changes have occurred in the fundamental characteristics.

Important features for processing, such as fine particle retention, or for application such as density or mechanical strength are not hindered by the incorporation of wastes.

Even with a preliminary character, one can state that a contribution for sustainability is given to two different industrial sectors by this approach.

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5 REFERENCES

Anjos, A.S. et al. (2003), *Compósitos à base de cimento reforçados com polpa celulósica de bambu. Parte I: Determinação do teor de reforço óptimo,* Revista Brasileira de Engenharia Agrícola e Ambiental, v.7, n.2, p. 339-345.

Coutts, R.S.P.; Ni, Y. (1995) *Autoclaved bamboo pulp fibre reinforced cement, Cement and Concrete Composites,* vol.17, p.99-106.

Podobnik E; Zule J; Cernec F.; (2006) *Papermill sludges. A secondary raw material, not waste,* Papir, vol. 34, no. 1, pp 25-27.

Standard Methods for the examination of water and wastewater 2450-D (1998), 20th Edition, p.2-54 to 2-58.

Application of crushed glass residues in mortars

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ABSTRACT: The need to add value to wastes and the opening towards the use of cement replacement materials, both in mortars and concretes, with the purpose of promoting increased sustainability of building materials, were the grounds for this work that aims the formulation of mortars with crushed glass residues. Flat construction glass is a material with a high percentage of amorphous silica, favouring pozzolanic reactivity. This property was evaluated using a chemical test based on the standard EN 196-5 - Methods of testing cement - Part 5: Pozzolanicity test of pozzolanic cement. The results obtained by this test indicate the material's capacity to react with calcium hydroxide, forming hydrated calcium alumino-silicates. Mortars with several binders (air-lime, hydraulic lime and cement) and this waste were formulated and tested in terms of mechanical strength. Results indicate pozzolanic reactivity of this waste and open possibilities for the use of this material in mortars.

1 INTRODUCTION

Pozzolans are materials of current use in mortars and concrete. Their main purpose is usually the mitigation of Alkali Silica Reaction (ASR), especially deleterious in concrete structures, which is achieved by the development of a faster pozzolanic reaction. Moreover, they are incorporated as cement (or binder) replacement materials, conferring additional strength to mortars and concretes, again due to the pozzolanic reaction, in which pozzolanic materials will react with the free $Ca(OH)_2$ originating from the binder (lime, hydraulic lime) or from hydration reactions (cement), creating calcium silicate and/or aluminous-silicate hydrates, that contribute towards a more resistant chemical structure. The formation of these reaction products also allows mortars with an air lime binder, with added pozzolans, to harden under water or in very high relative humidity conditions.

When finely ground, these materials attain a higher specific surface and therefore, become more reactive. Furthermore, this fineness confers additional strength to mortars by increasing their compacity.

Various materials of natural or artificial origin may be used as pozzolans, depending mainly on their content in amorphous silica and, therefore, potential to develop a pozzolanic reaction. Many waste materials have pozolanic properties and there is an opening toward their use as pozolanic additions (Polettini, Pomi & Carcani, 2004, Taha & Nouno, in press, Tay, 1990, Terro, 2005), contributing towards environmental sustainability. Waste glass is a potential material for this purpose as abundant glass residue is available and its composition favours pozolanic reaction. Glass may produce ASR and this has been a major drawback for its use in cementitious materials, but recent studies suggest that finely ground glass produces a fast pozolanic reaction inhibiting ASR (Terro, 2005). Recently, efforts to characterize and re-use waste glass as cement or aggregate replacement have already been made, with some positive results (Özkan & Yüksel, in press, Taha & Nuonu, 2006, Terro, 2005, Shi, Wu, Riefler & Wang, 2004).

The use of waste materials in mortars can be an important step towards sustainability as the construction industry is significant and mortars worldwide use cement as their main binder; the use of alternative mortars with binders that are less pollutant and/or the use of residues could impact the mortar industry towards the production of mortars with less environmental impact. In order to achieve this, mortars must have adequate characteristics to be used as renders and/or as joint mortars, implying that certain mechanical characteristics and water behaviour must be achieved. This paper deals with the issue of mechanical characterization, especially focusing on the pozzolanic effect of the glass residue.

2 CHARACTERIZATION OF GLASS RESIDUE

A fine glass powder, from flat glass wastes was used. It was characterized in terms of Blaine's specific surface using a Blaine apparatus, mineral composition, using X-Ray Diffraction (XRD) and chemical composition using X-Ray Fluorescence (XRF). These analyses revealed a specific surface of 3060cm^2/g, an amorphous material by XRD and a chemical composition (Table 1) of SiO_2 (74%); Na_2O (12,5%) and CaO (8,5%), typical of a plane sodocalcic glass.

Table 1: Chemical characterization of glass residue by FRX (main constituents)

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
Percentage by mass	73,99	1,02	0,18	8,56	3,33	12,55	0,24

These characteristics, a high specific surface, an amorphous material and a high content in silica indicate a reactive pozzolan. However, a pozzolanic reactivity test was performed following standard EN 196-5 - Methods of testing cement - Part 5: Pozzolanicity test of pozzolanic cement. This test is based on the chemical reaction between the pozzolan and calcium hydroxide produced by the hydration reaction of cement: after mixing a certain quantity of cement and pozzolan in a solution that is kept for 8 to 15days, the amounts of CaO and OH^- are measured. A high consumption of $Ca(OH)_2$ indicates a strong pozzolanic reaction. Results obtained with the glass residue point towards its strong pozzolanic potential.

3 MORTAR FORMULATION AND CONDITIONING

Mortars with three different binders: cement, hydraulic lime and air lime were formulated. A comparison mortar, with no glass residue (named C, HL, L), was used for each case. These formulations, in weight, were chosen taking into account mortars of current use. With the addition of glass residue and although it is most probable, due to the characterization that was undertaken, that the glass residue will act almost totally as a binder, a 1:1:4 (air lime: glass residue: sand) proportion was used with air lime. With the other binders, cement (C) and hydraulic lime (HL), two different glass proportions were used taking into account possible performance as binder or aggregate. Formulations are listed in Table 2.

Table 2: Mortars composition

Mortar	Air Lime (L)	Cement (C)	Hidraulic Lime (HL)	Glass Powder (G)	Sand (S)
C	-	1	-	-	4
CG1	-	1	-	0,5	4,5
CG2	-	1	-	1	5
HL	-	-	1	-	3,5
HLG1	-	-	1	0,5	4,5
HLG2	-	-	1	1	4
L	1	-	-	-	3
LG	1	-	-	1	4

Conditioning was performed according to standard (NP EN 1015-11: Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar) with a temperature of 20±2ºC and a relative humidity of 65±5ºC.

4 CHARACTERIZATION TESTS

In order to determine mechanical characteristics of the formulated mortars a testing campaign was undertaken and all samples were submitted to flexural and compressive strength tests following standard NP EN 1015-11: Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar. The dynamic modulus of elasticity was determined following Rel. LNEC 289/95NCCt (Figure 1). Testing was performed at the ages of 7 days, 28 days and 90 days.

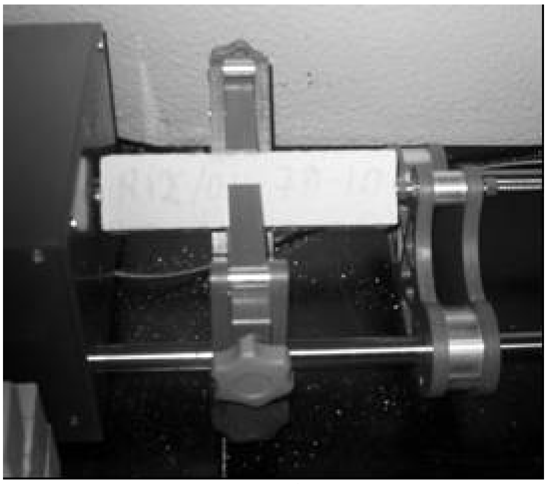

Figure 1 – Measurement of the dynamic modulus of elasticity

5 RESULTS AND DISCUSSION

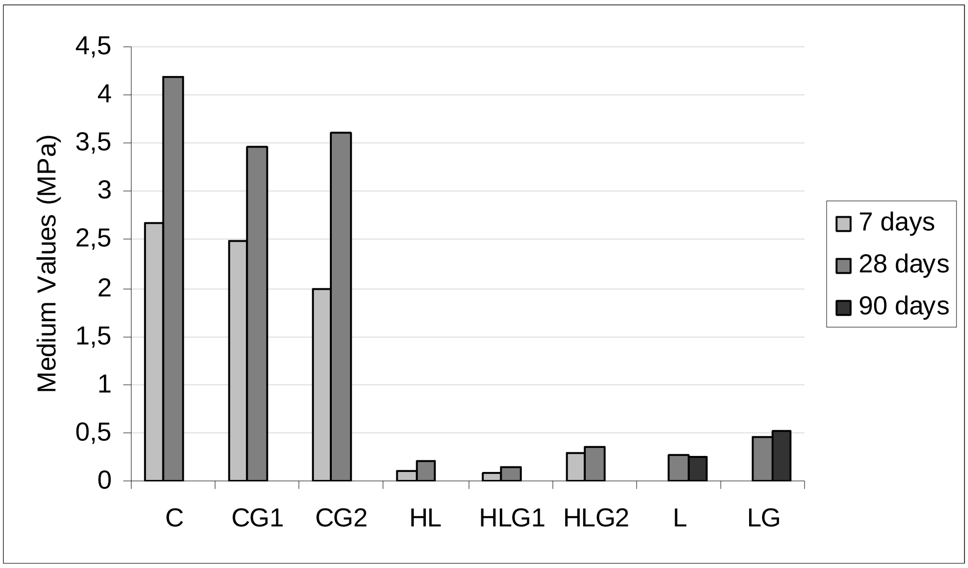

Figure 2 – Flexural strength of mortars at 7, 28 and 90 days

In mortars with cement as binder (C, CG1, CG2) there is a decrease in flexural strength with glass residue addition. However, in both hydraulic lime and air lime mortars, glass residue created an increase this mechanic characteristic.

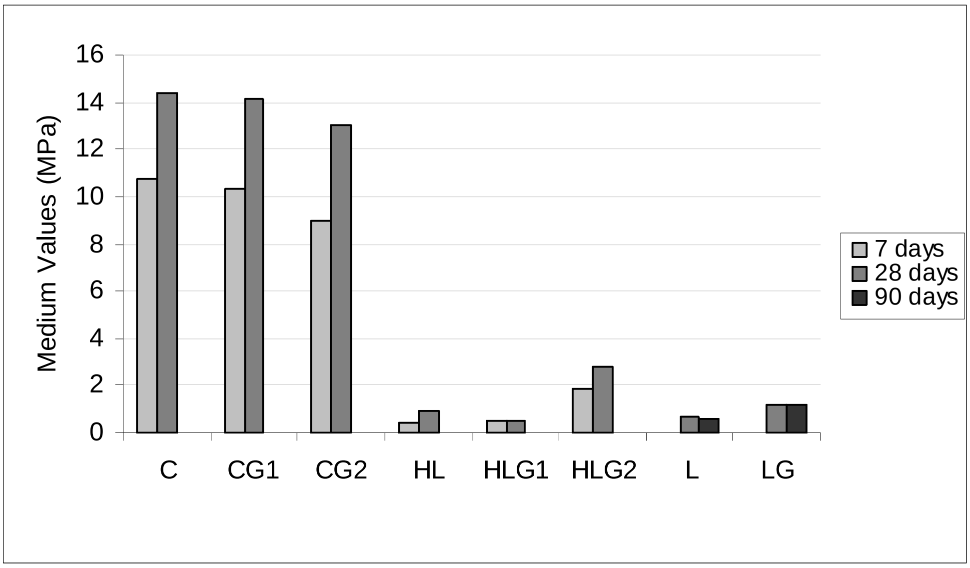

Figure 3 – Compressive strength of mortars at 7, 28 and 90 days

Results show, similarly to those of flexural strength, that incorporation of glass residue reduced mechanical strength in cement mortars, and increased this property in mortars with air lime or hydraulic lime binders.

Pozzolans react with avaliable CH, mainly producing CSH similar to that produced in cement hydration reactions. In the case of cement mortars, not much CH is available, possibly forcing glass residue to act as an aggregate. In these mortars a lower percentage of pozzolan will probably increase mechanical strength.

In lime and hydraulic lime mortars glass residue acts as a pozzolanic addition conferring increased mechanical strength.

6 CONCLUSIONS

Glass powder from flat glass waste can be used as a pozolanic material, due to its pozzolanic reactivity. In air lime or hydraulic lime mortars, the addition of glass residue increases mechanical strength. Contrarily, in cement mortars there is a decrease of mechanical strength with the addition of glass residue. A reason for this may be the lack of calcium hydroxide for reaction purposes, inducing the pozzolan to act as an aggregate. The effect of ASR is highly improbable due to the time span and thermal and hygrometric conditions. However, further studies on the chemical reactions developed must be undertaken.

Glass residue is a promising addition for use in mortars, which will are being subject to an enlarged testing campaign, taking into account their behaviour in terms of water absorption, their drying capacity and their cracking susceptibility. These tests will enable a complete characterization and an evaluation of application possibilities.

ACKNOWLEDGEMENTS

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REFERENCES

Özkan, Ö. & Yüksel. Construction and Building Materials, in press.
Polettini, A., Pomi, R. & Caracni, G. 2005. The effect of Na and Ca salts on MSWI bottom ash activation for reuse as a pozolanic admixture. Resources, Conservation and Recycling 43: 403-418.
Shi, C., Wu, Y., Riefler, C. & Wang, H. 2005. Characteristics and pozolanic reactivity of glass powders. Cement and Concrete Research, 35: 987-993.
Taha, B. & Nounu, G. Construction and Building Materials, in press.
Tay, J. 1990. Ash from oil-palm waste. Journal of Materials in Civil Engineering 2 (2): 94-105.
Terro, M.J. 2005. Properties of concrete made with recycled crushed glass at elevated temperatures. Building and Environment 41: 633-639.

Optimization of pozzolanic reaction of ground waste glass incorporated in cement mortars

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ABSTRACT: This paper examines the possibility of using finely ground waste glass of the three most common coloured glass bottles used in Portugal as partial cement replacement in mortar and concrete. The pozzolanic activity of ground glass was optimised as function of different particle size. The reduction of waste glass particle size was accomplished in the laboratory by crushing and grinding the waste glass using a jar mill. The particle fineness, to obtain a required reactivity, was studied as function of grinding time. The compressive strength activity index, at 7, 28 and 90 days, was determined for different ground waste glass particle size and partial cement replacement percentage in mortar. Test method described in ASTM C 1260 was applied to verify the potential expansion caused by the alkali silica reaction.
The results obtained confirm the pozzolanic activity of the ground waste glass of different colour collected in central region of Portugal.

1 INTRODUCTION

Nonrecyclabe waste glass constitutes a problem for solid waste disposal in many municipalities in Portugal. Traditionally, most nonrecyclabe mixed-colour broken glass is coming from the bottling industry. The current practice is still to landfill most of the nonrecyclabe glass. Since the glass is not biodegradable, landfills do not provide an environment-friendly solution. By the other hand, in Portugal, the pozzolanic materials begin to be not enough to supply all the demands of the construction industry. Nowadays, the civil construction industry search the alternatives for satisfy the increasing needs for the cement and concrete production.

In Portugal, used bottles are partially reutilized. They are collected, sorted, and crushed to be used mostly as a raw material for new bottles. However it is estimated accordingly to relatively recent data that only 30% of the total used bottles are actually currently being recycled (Sousa L, 1995).

Efforts have been made in the concrete industry to use waste glass as partial replacement of coarse or fine aggregates. However, due to the strong reaction between the alkali in cement and the reactive silica in glass (ASR reaction), studies of the use of glass in concrete as part of the coarse aggregate were not always satisfactory due of the marked strength reduction and simultaneous excessive expansion (Shao et al, 2000, Johnson, 1974).

Recent studies have shown that the particle size of glass is a crucial factor for ARS reaction to occur (Karamberi & Moutsatsou, 2005). In particular, aggregate fineness favours ASR expansion since the ASR reaction is a surface area dependent phenomenon. It seams that exists a minimum particle size, depending on the structure of the glass, where the maximum expansion occurs. It was found that if the glass was ground to a particle size of 300 µm or smaller, the alkali-silica reaction (ASR) induced expansion could be reduced (Meyer et al. 1996). In fact, data reported in the literature show that if the waste glass is finely ground, under 75 µm, this effect does not occur and mortar durability is guaranteed (Shao et al., 2000).

It also well know that typical pozzolanic materials might features high silica content, an amorphous structure and have a large surface area.

Taking into consideration all the above factors this paper presents a study on the assessment of the pozzolanic activity of green, amber and flint color waste glass as a component of cementitious materials used as filler or binder in mortar and concrete.

2 MATERIALS AND METHODS

2.1. Materials

The waste glass used in this study was obtained at the waste management and disposal service of Cova da Beira Municipal Association, of interior region of Portugal. The chemical composition of the glass was analyzed using an X-ray microprobe analyzer and is listed in Table 1.

Table 1. Chemical compositions of ground waste glass (by weight percent)

	Flint glass	Amber glass	Green glass
Na_2O	9.94	10.37	10.54
MgO	0.75	0.81	1.18
Al_2O_3	2.57	3.09	2.54
SiO_2	74.07	73.27	72.25
Cl_2O	-	-	-
K_2O	1.14	1.10	1.15
CaO	11.53	11.36	12.35
TiO_2	-	-	-
Fe_2O_3	-	-	-
SO_3	-	-	-

The three types of colored glass have a similar percentage of reactive silica, around 74%. In accordance to NP EN 450 (1995), the glass satisfies the basic chemical requirements for a pozzolan, namely to have a high percent of silica. However, it does not meet the optional requirement for the alkali content because of the high percentage of Na_2O in glass.

Koslova et al, 2004, observed that the introduction of unwashed glass as aggregate exhibits the risk of predicting a false reactivity of multi-component systems increasing the reactivity of tested systems. Thus, the glass used in this work was previous washed before mixing.

To verify the physical requirement for fineness, the glass was grinded in jaw crusher and ball mill, and separated by sieving in three different particle size ranges, as follows: 75µm – 150µm, 45µm – 75µm and < 4µm. The purpose of this size selection was to observe the effect of maximum size related to the minimum grinding time which the pozzolanic activity can be present in a cementitious matrix without a significant alkali silica expansion reaction. The optimization of the grinding time versus particle size obtained with the grinding process was controlled with the determination of Blaine surface area. Figure 1 shows typical micrographs used to analyze the particle size and particle shape of the ground glass obtained in the scanning electron microscope (SEM). In this figure, the ground waste glasses, after grinding, exhibit angular shapes and it is possible to observe a more homogeneous size distribution for 0 - 45µm size range than for 45µm – 75µm size range.

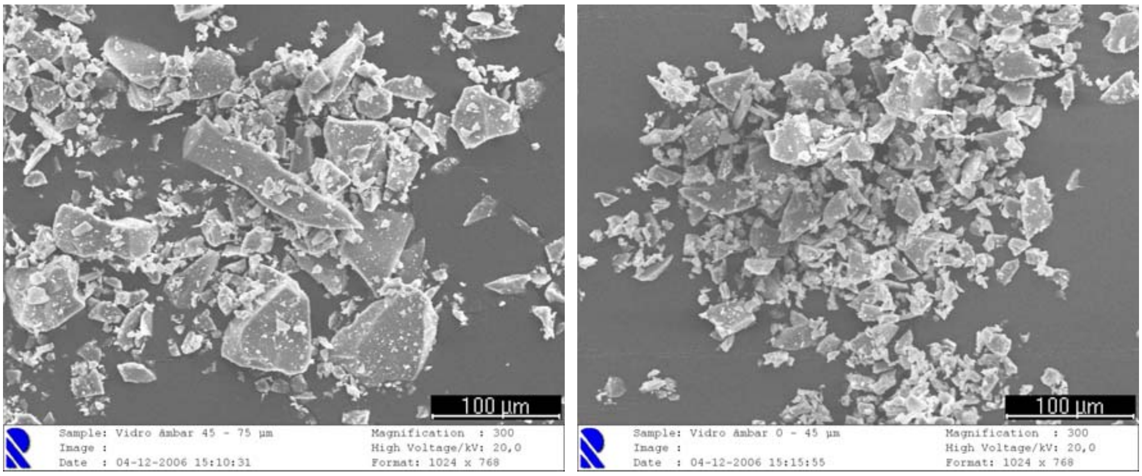

Figure 1. Particle size and shape of ground waste glass of 45 - 75µm (left) and 0 - 45µm (right) particle range, after grinding.

A commercial Portland cement type CEM I 42.5R conforming to European Standards NP EN–197-1 with Blaine fineness of 400.9 m^2/kg and with a particle density of 3140 kg/m^3 was used at all different mixes.

As aggregate for producing mortars, natural sand was used with maximum particle size 4.76mm, a particle density of 2450 kg/m^3 and Modulus of Fineness of 2.97.

2.2. Mixture details

The mortar mixtures were produced with the weight ratio of 1: 3: 0.5 (binder: sand: water). The cementitious material consisted of Portland cement blended in laboratory with each of the three different color waste glasses. Thus, Portland cement was partially replaced by 10%, 20%, 25%, 30% and 40% of each color and size grinded ground waste glass. The mortars mixture proportions used are reported in Table 2.

The control of fresh mortar consistency using the flow-table test conform the EN 1015-3 allowed verifying the influence of glass fineness and cement percentage replacement on the fresh workability for all the tested mortars.

2.2. Mechanical strength of mortars

For each mortar mixture, prismatic specimens of 40 x 40 x 160 mm were manufactured, cast, wet cured for 7, 28 and 90 days. Both compressive and flexural strength were evaluated in conformance with EN 196-1. The results obtained are reported in Figures 2 and 3.

2.3. ASR test method

Study of expansion due to the possible reaction between the alkali in cement and silica in the glass was done in accordance with ASTM C1260. Mortar bars of 40 x 40 x 160 mm sizes were made of standard graded river sand, type CEM I 42.5R Portland cement, and grinded ground waste glass. After 24 h of curing, the bars were placed in water at 80º C for another 24 h to gain a reference length. They were then transferred to a solution of 1 N of NaOH at 80º C. Length bar readings were then taken every day for 14 days. The mortar bars without grinded ground waste glass were also tested as control. The comparison with the control is an indication of whether or not the silica in glass is reactive with the alkali in cement and of the solution. The results obtained are reported in Figure 6.

2.4. Grinding time optimization

The grinding time optimization was performed determining the Blaine specific surface at the end of a certain time of grinding in ball mill of samples previously prepared by a jaw crusher.

The Blaine specific surface was determined at end of each ball mill grinding hour for a total duration of 10 hours. The partial results obtained in this study are shown in Figure 7.

3 RESULTS AND DISCUSSON

3.1. Mechanical strength with various glass powders content

The compressive strength results of 75 – 150μm glass powders mortars are plotted in Figure 2. It can be observed, in case of cement replacement by the glass powder, the reduction in compressive strength increases with the level of cement replacement.

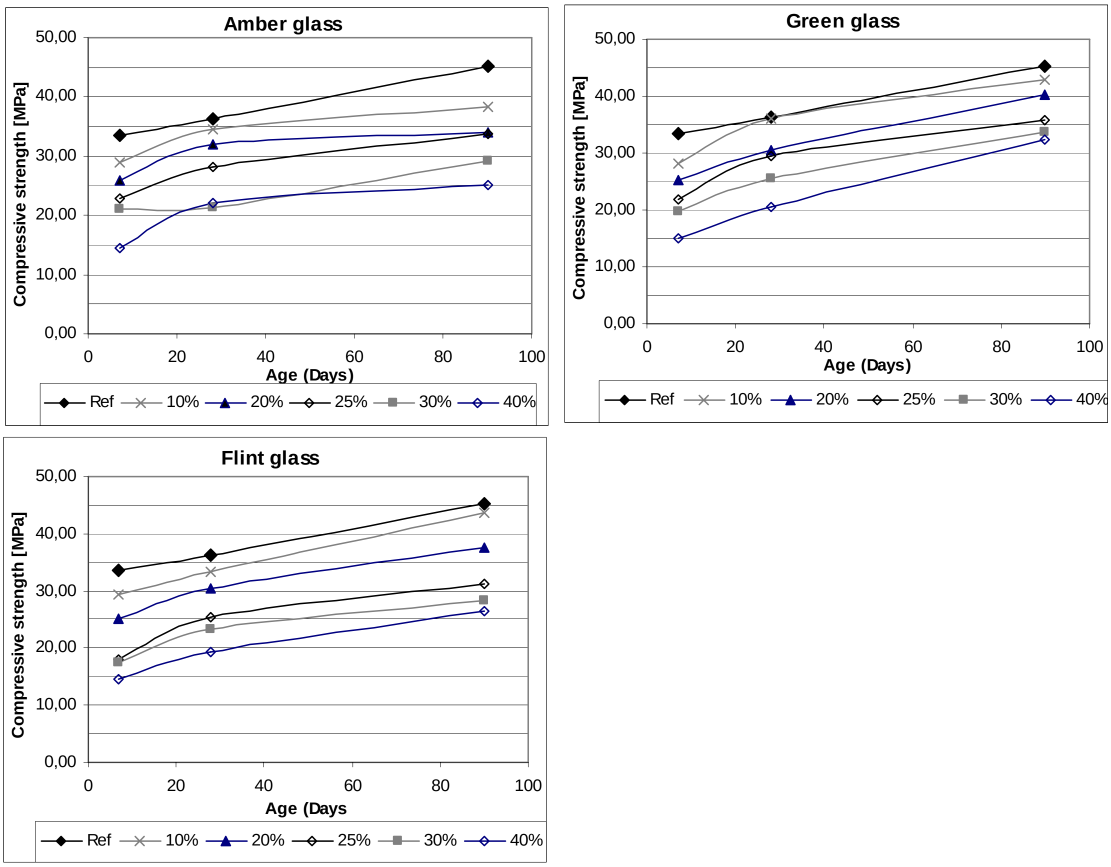

Figure 2. Compressive strength development of glass powders 75 – 150 μm

Figure 3 shows that increasing of compressive strength is obtained with reduction of the glass powder particle sizes. For particle sizes low than 45 μm, the compressive strength of mortar with 25% of cement replacement is closer to the control mortar analogous results.

The result of compressive strength obtained in mortar with different glass color, when analyzed for the same particle glass size range, is similar for amber and flint glass. Mortars containing green color glass powders, in turn, have the highest compressive strength for all particle sizes. This difference is due to the fact that specific surface of the green glass (of about 445 kg/m^2) is slight higher of amber and flint glass (of about 355 kg/m^2).

According to NP EN 450 the pozzolanic activity is evaluated by a strength activity index correspondent of 75% and 85% at 28 days and 90 days, respectively, obtained for a mortar with 25% of cement replacement.

The strength activity index is plotted in Figures 5 and 6. The results presented there show that at 28 days the amber glass attaint a compressive strength higher than the results of 75% control mortar strength for all glass particle size range studied here. In the case of 90 days requirement only the 75 – 150 μm particle range did not attaint the 85% pozzolanic activity index. The green glass powder mortars have a compressive strength higher than 75% at 28 days for all particles size ranges. At 90 days the index of 85% is not attaint for the range of 75 – 150 µm particle, but it is highest for 0 - 45 µm and 45 - 75 µm particle ranges.

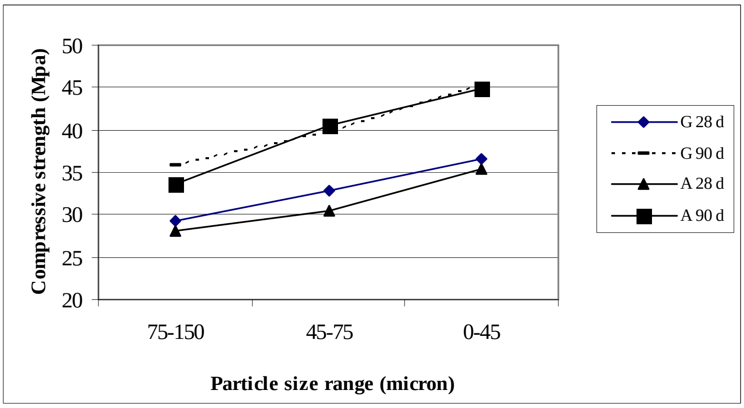

Figure 3. Compressive strength of mortars with different particle size range (G – green glass, A – amber glass)

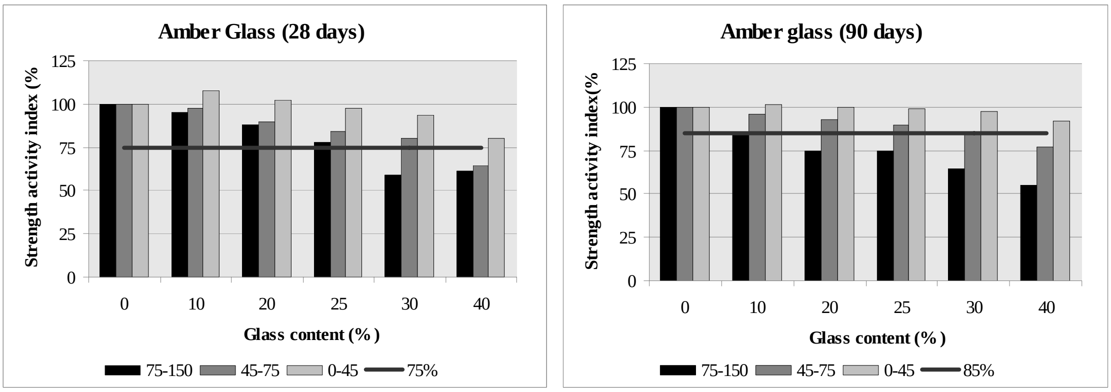

Figure 4. Strength activity index for amber glass mortar

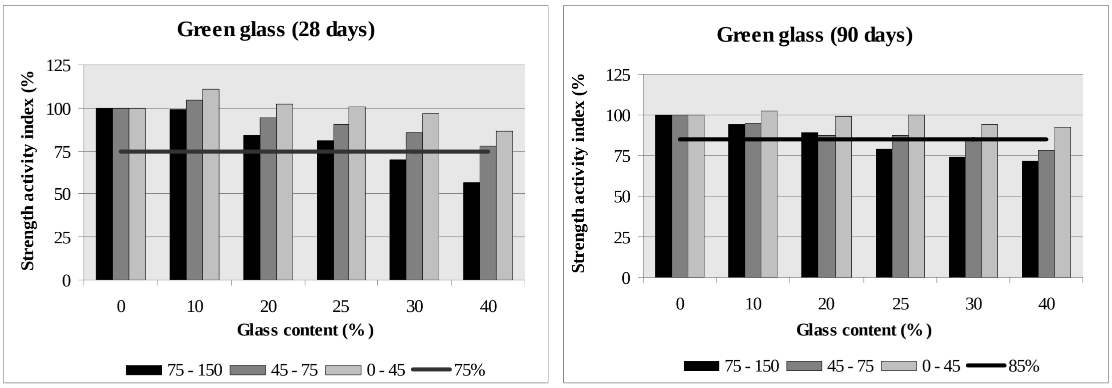

Figure 5. Strength activity index for green glass mortar

The expansion results obtained by the measurements complying with ASTM C1260 in terms of colors waste glasses (amber, green and flint) are partials, but present a trend tendency which confirms the results obtained by Shayan and Xu, 2004, where the expansion for all mortars molded with the different ground glass used in this study is farly lower than the maximum value of 0,1% prescribed in standard specifications. Figure 6 shows that mortar with 25% of cement replacement by the amber ground glass has the highest expansion of all samples tested. This high expansion value is due to the cement content in the mortar which, in turn, is higher than for other mortars prepared with amber ground glass powders.

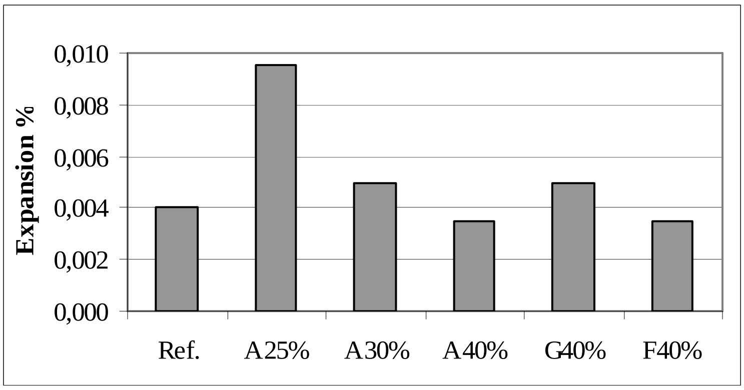

Figure 6. Expansion for mortar bars

Figure 7 shows a linear tendency of the increasing of glass powders fineness measured by the Blaine apparatus. After 9 hours grinding time in a ball mill, it is possible to obtain powders particles sizes that gives a specific surface higher than 250 m^2/kg. This Blaine surface area is a characteristic of the particles that can be classified as being of 45 - 75 µm size range.

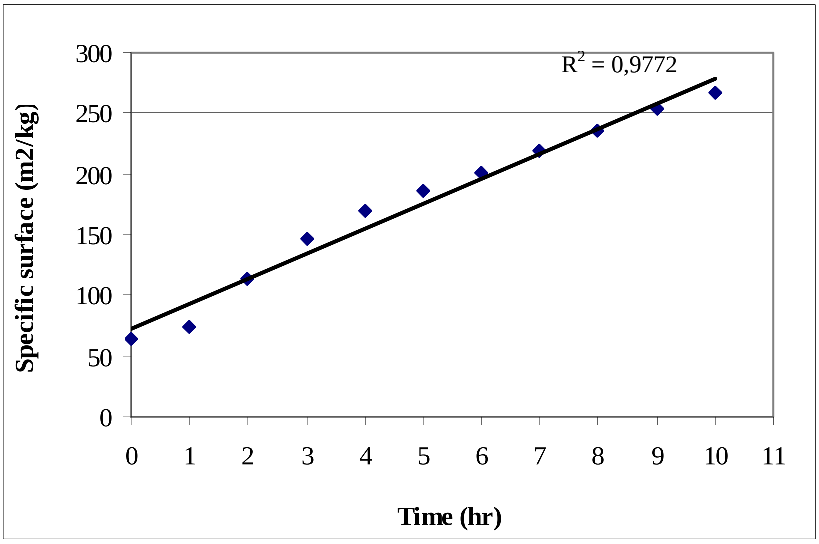

Figure 7. Blaine specific surface as function of grinding time

4 CONCLUSIONS

The aim of this study was to evaluate the “recyclability” of domestic ground waste glass, collected in the municipal service of Portugal interior region, as a cement replacement for mortar and concrete. A basic experimental study on the physical and mechanical properties of mortars containing recycled waste glass as pozzolan material provided the following results and conclusions:

The determination of the oxide contents of selected waste glass samples indicates that, in accordance to NP EN 450, the glass satisfies the basic chemical requirements for a pozzolan. However, it does not comply with the additional requirement for the alkali content because of the high percentage of Na_2O in glass. Despite this situation, finely ground glass powders, higher than 250 m^2/kg Blaine specific surface, exhibited very high pozzolanic activity.

It was also verified that the for finer glass powders, mortars pozzolanic activity is higher. It has been also concluded that 30% of 45 - 75 µm ground waste glasses size range could be incorporated as cement replacement in mortar or concrete without any detrimental effects caused by the expansivity provoked by the alkali silica reaction.

The results present in this paper show that is a great potential for the utilisation of waste glass in mortar and concrete as a partial replacement for expensive materials such as silica fume, fly ash and cement.

5 ACKNOWLEDGEMENTS

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6 REFERENCE

ASTM Standards. 1994. Volumes 04.01 and 04.02, American Society for Testing and Materials, Philadelphia, PA.

Johnson C.D. 1974. Waste glass as coarse aggregate for concrete, J Testing and Evaluation 2 (5): 344–350.

Meyer C., Baxter S., Jin W. 1996. Alkali-silica reaction in concrete with waste glass as aggregate. in: K.P. Chong (Ed.), Materials for a New Millennium, Proceedings of ASCE Materials Engineering Conference, Washington, D.C., pp. 1388–1394.

Meyer C., Baxter S., Jin W. 1996. Potential of waste glass for concrete masonry blocks, in: K.P. Chong (Ed.), Materials for a New Millennium, Proceedings of ASCE Materials Engineering Conference, Washington, D.C., pp. 666–673

Karamberi A. & Moutsatsou A. 2005. Participation of coloured glass cullet in cementitious materials. Cement & Concrete Composites 27 : 319–327

Kozlova S., Millrath K., Meyer C., Shimanovich S. 2004. A suggested screening test for ASR in cement-bound composites containing glass aggregate based on autoclaving. Cement & Concrete Composites 26 : 827–835

Shao Y, Lefort T, Moras S, Rodriguez D. 2000. Studies on concrete containing ground waste glass. Cement and Concrete Research 30: 91–100

Shayan A.& Xu A. 2004.Value-added utilisation of waste glass in concrete. Cement and Concrete Research 34 : 81–89

Sousa L. 1995. Reciclagem de vidro em embalagem. Revista AEP Ambiente (2): 1-3

Chemical characterization and leaching of treated fly ash from a MSWI plant

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ABSTRACT: With the aim of reducing landfill deposition the incorporation of industrial waste into the cement matrix of building materials is becoming common practice. An assessment of the elements and compounds present in the waste that have a detrimental effect on cement hydration or on the environment, such as lead, zinc, chromium and sulphates, should always be performed.

Fly ashes from the heat recovery and air pollution control systems of MSWI plants are classified as hazardous wastes owing to the concentration of potentially hazardous heavy metals as well as their high salt content. Waste pre-treatment represents a possible approach to prepare these residues for incorporation into building materials as it will reduce their pollution potential.

This paper presents the results of the chemical characterization of two fly ash mixtures, collected at different locations from a Portuguese MSWI plant, before and after a selected pre-treatment, and an evaluation of their leaching behaviour.

1 INTRODUCTION

Nowadays, there are growing pressures to use waste materials within the construction sector. This use of wastes in civil engineering requires an evaluation of both the environmental and technical suitability of the waste. From the environmental point of view the main concern is the leaching out of hazardous substances, such as heavy metals, to soil and water supplies while from the technical point of view issues like changes in cement hydration, durability analysis and economic evaluation should be addressed.

Extensive research has been performed in to the use of solid residues from municipal solid waste incineration (MSWI) as cement or aggregate replacement in building materials (Al-Rawas et al., 2005, Aubert et al., 2006, Collivignarelli & Sorlini, 2002, Huang & Chu, 2003, Juric et al., 2006, Lin et al., 2003, Reijnders, 2007, Wainwright, 2000). Municipal solid waste (MSW) generation in Europe increased at an annual rate of 2% from 1995 to 2003 and, in 2003, 17.3% of these wastes were incinerated (Eurostat, 2005). Solid residues from MSWI have different chemical compositions and can be broadly classified as bottom ash and fly ash. Bottom ash is recovered from the base of the combustion chamber and fly ash from the heat recovery and air pollution control systems. Incineration of a tonne of municipal solid waste generated, on average, 200 to 300 kg of bottom ash and 25 to 50 kg of fly ash (Chandler A. J., 1997).

Owing to stringent air emission policies, fly ash which contains high contents of soluble salts, such as calcium carbonate, sodium and potassium chlorides and sulphates, heavy metals and residual amounts of organic composites are classified as hazardous waste (Ferreira et al., 2005, Wan et al., 2006). In order to upgrade MSWI fly ash to a usable product it is essential to use preliminary treatments that minimize the prejudicial effects of some of these compounds. The composition of MSWI fly ash varies from plant to plant and it is not possible to establish a universal treatment for them (Derie, 1996). At present, suggested treatments can be divided into three main categories: stabilization/solidification (S/S), thermal treatments and extraction treatments (Alba et al., 2001, Chan et al., 2000, Chimenos et al., 2005). Experiments involving a combination of the aforementioned processes have been applied to MSWI fly ash in order to upgrade them for incorporation in building materials (De Casa et al., 2007, Mangialardi, 2001).

Stabilization/solidification (S/S) of MSWI fly ash is the most common treatment and is successful due to the chemical and physical processes that occur between the residue and a binder. When cement is used as a binder it produces changes in the speciation and solubility of the contaminants as they interact with the cement hydration products; physical adsorption and encapsulation can take place (Batchelor, 2006, Malviya & Chaudhary, 2006, Qiao et al., 2007). A major disadvantage of S/S is the increase in porosity and permeability of the solidified structure with time and the consequent reduction in strength, due to the leaching of large amounts of soluble salts. Another drawback of S/S lies on the increase of weight and volume of the residue after treatment (Geysen et al., 2004).

Thermal treatments are not as common as S/S owing mainly to the large input of energy required that make them very costly. By heating below or at the melting temperature the chemical and structural properties of the residue are changed and the vitreous or crystalline slag formed can be usefully applied as a construction material (Sakai & Hiraoka, 2000).

Extraction treatments involving different media lead to an efficient reduction in salts content (Abbas et al., 2003, Ferreira et al., 2005, Hong et al., 2000). Water-based extraction is the simplest process to treat MSWI fly ash. The efficiency of this treatment relies on the type of residue and on the liquid to solid ratio (L/S). According to Derie a liquid to solid ratio between 5 and 10 and a washing time of 1 hour will remove soluble alkali chlorides and some calcium sulphate without solubilising to a great extent the undesirable metals (Derie, 1996). Wilewska-Bien et al prooved the feasibility of water extraction treatment with an L/S equal to 3, 5 and 10 in a pilot plant (Wilewska-Bien et al., in press). Abbas et al. reported the removal of salts in MSW fly ash from fluidized bed incinerators using L/S of 1,2 and 4 with extraction times of up to 60 minutes (Abbas et al., 2003). The main drawback of water extraction is the generation of an effluent whose characteristics need to be evaluated before it is discharged to surface waters.

The aim of this research is to define a preliminary treatment, using water as the extractant media that will reduce the level of salts in MSWI fly ash to a level that does not impair their incorporation into concrete and reinforced concrete. This paper reports the chemical and mineralogical characterisation of two fly ashes from a Portuguese MSW incinerator according to their leaching behaviour and the effects of the selected treatment on the content of chloride, sulphate, chromium, copper, lead and zinc.

2 MATERIALS AND METHODS

2.1 *Fly ash*

The fly ashes used in this study were collected from two distinct locations, depicted in Figure 1 as I and II, of a Portuguese MSW incineration plant. The unit is a mass burn waste-to-energy facility, with a capacity of 2000 tons/day, using semidry scrubbers and fabric bag-house filters for emissions control. During three days, ash identified as Ash I (comprising a combination of ashes from the hopper of the boiler and of the economiser) and Ash II (a mixture enclosing Ash I, semidry scrubber ash and fabric filter ash) were sampled and stored in dry and sealed containers.

2.2 *Chemical and mineralogical characterisation*

To evaluate the chemical composition of the fly ash samples they were first ground with a HERZOG HSM 50 vibrating grinding mill. They were then passed through a 90 μm sieve, mixed with wax (wax/ash ratio of 0.6) and pressed into pellets using a HERZOG press by applying a 200kN force for 30 s. The oxide composition was obtained using a wavelength X-ray fluorescence spectrometry, with an AXIOS/PANANALYTICAL spectrometer. Sulphate content, expressed as SO3, was determined by gravimetry and chloride content by titrimetry.

Figure 1. MSW incinerator: 1 Furnace; 2 Boiler; 3 Superheater; 4 Economiser; 5 Scrubber; 6 Fabric filter baghouse; 7 Stack

The crystalline structure of the fly ash was assessed using an X-ray difractometer at 35 kV and 45 mA using Co Kα radiation and 10-60º 2θ range. Before the X-ray diffraction (XRD) analysis was performed the fly ash was passed through a 106 μm sieve.

The water content, Wc, of the fly ashes was tested by weighing 10 g samples and drying at 105 ºC until a constant mass was reached.

Loss on ignition, LOI, was determined from samples of 1 g at 950 ºC until constant mass was reached.

2.3 *Leaching test*

The European compliance leaching test EN 12457-2 (CEN, 2002) for granular waste materials was performed on untreated fly ashes. Demineralised water was used as the leachant at a liquid to solid ratio (L/S) of 2 l / kg and a leaching time of 24 h. The leachate was recovered after filtration over a 0.45 μm filter and acidified with ultra-pure nitric acid. Heavy metals concentration was determined using an inductively coupled plasma – atomic emission spectrometer, ICP-AES Jobin Yvon 24, and a graphite furnace atomic absorption spectrometer, GBC 904 GFAAS. Chlorides and sulphates were quantified by titrimetric and gravimetric methods.

2.4 *Fly ash water extraction*

The soluble salts content of the fly ashes was reduced by mixing the residues with distilled water and following three different stirring regimes:

– One washing step with L/S ratio 2 l / kg and extraction time of 15 minutes;
– Three washing steps with L/S ratio 2 l / kg and extraction times of 5 minutes;
– Two washing steps with L/S ratio of 5 l / kg and extraction times of 5 minutes.

In sequential washing steps, the solids were allowed to settle and the supernatant liquid was filtered. The material retained on the filter was recovered and mixed with the solid.

The chlorides and sulphates concentration in the water extracts were obtained by titration and gravimetry, respectively. A quantitative analysis for the heavy metals was performed by ICP-AES and GFAAS.

3 RESULTS AND DISCUSSION

3.1 *Chemical and mineralogical characterization*

Table 1 shows the composition of the untreated fly ashes expressed as metal oxides; calcium is the major metal. The main difference between the ashes is the higher content of silica in Ash I, which is twice the value of Ash II, and the level of chlorides in Ash II, which is about five times more than Ash I. As stated in the Introduction, the high chloride and sulphate content make these ashes unsuitable for use in concrete and so they must be subjected to preliminary treatment. Regarding the heavy metals, zinc is the most concentrated element in the two ashes. Loss on ignition is high on both ashes, especially in Ash I.

Table 1. Semi-quantitative analysis of untreated fly ashes.

Oxides	I	II
	%	%
Al_2O_3	7.5	4.0
CaO	49	42
SiO_2	19	7.5
Na_2O	3.2	6.8
MgO	1.8	0.84
K_2O	2.2	5.3
Fe_2O_3	3.2	1.4
TiO_2	3.1	1.5
Cl	4.3	20
SO_3	3.1	5.5
CrO_3	0.12	0.062
MnO_2	0.14	0.092
NiO	0.035	0.025
CuO	0.10	0.10
ZnO	0.54	0.84
SrO	0.086	0.053
Sb_2O_3	0.025	0.089
BaO	0.22	0.12
PbO	0.056	0.28
CdO	–	0.016
LOI	9	20
W_c	0.19	1.2

The mineralogical composition of Ash I and II is very complex. The low intensity of the peaks in the X-ray diffraction analysis show that most of the compounds in the ashes are mainly in the amorphous form. The main differences between the ashes observed in the semi-quantitative analysis are confirmed by the XRD results. The higher height of the quartz (α-SiO_2) peak in the X- ray diffractograms show the high level of SiO_2 in Ash I in relation to Ash II. The high concentration of chlorides in Ash II in relation to Ash I is observed through the higher height of the crystalline forms of halite (NaCl), sylvite (KCl) and calcium chloride hydroxide.

The heights of the halite and sylvite peaks confirm that Na and K were present in large quantities in Ash II when compared with Ash I. The main crystalline forms of calcium, the major element in the ashes, are calcite (CaCO3) and anhydrite (CaSO4), however, it is possible to observe the presence of calcium as portlandite (Ca(OH)2), lime (CaO) and calcium silicate. Iron and titanium have been identified by the XRD analysis in the forms of hematite and titanium oxide. Regarding the presence of heavy metals, it was not possible to match any of the peaks for these elements, probably owing to their low content.

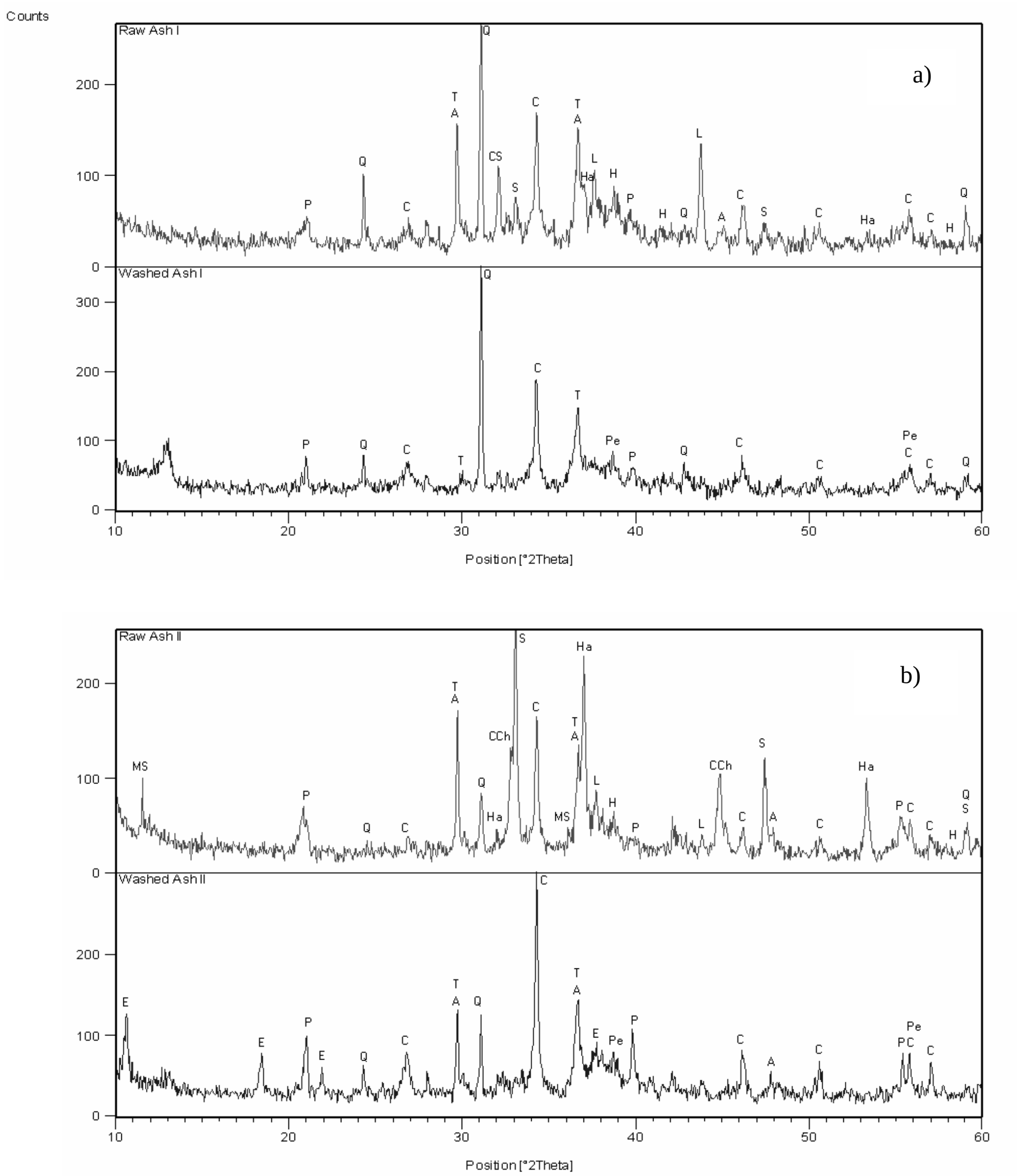


Figure 2. X-ray pattern for raw and washed fly ashes a) Ash I b) Ash II: Q-quartz, C-calcite, L-lime, P-portlandite, A-anhydrite, CS-calcium silicate, CCh-calcium chloride hydroxide, S- Sylvite, Ha-halite, H-hematite, T-titanium oxide, Pe-perovskite, MS-calcium monosulphoaluminate, E-ettringite

3.2 *Leaching test*

The leaching test used in this investigation is the recommended European Union compliance leaching test for granular waste. Table 2 shows the leachate content of chlorides, sulphates, and of selected heavy metals for untreated fly ashes as well as the regulatory limits for non-hazardous wastes (Nh) which are to be disposed of to landfill, according to Council Decision 2003/33/CE.

According to Table 2, untreated Ash II has higher contents of all the selected elements. The heavy metal most leached out was lead (0.5 % and 11.4% of the total concentration for Ash I and Ash II, respectively). For Ash I, only the chloride content exceeded the limit for non-hazardous waste though this ash is classified as hazardous waste. Ash II is also categorized as hazardous owing to the presence of Pb, Zn and Cl. The pH of the leachates was 12.5 and 12.2 for Ash I and II respectively. At these levels of pH there is an increase in solubility of hydroxides of zinc and lead (Chimenos et al., 2005).

Table 2. Leachate contents and limits for non-hazardous waste

Element mg / kg dry wt.	Ash I	Ash II	Nh limits
Cd	< 0.05	< 0.05	1
Cr	1	5	10
Cu	0.1	0.1	50
Pb	3	290	10
Zn	3	75	50
Cl	17075	133800	15000
SO_3	100	16200	20000

3.3 *Fly ash water extraction*

As can be seen from Table 3 the pH of the studied ashes during extraction is always very high. The higher content of lime in Ash I is responsible for the higher pH of the extracts when compared with Ash II.

Water extraction results in significant removal of chlorides from the fly ashes (Tab. 3). For Ash II, the highest amount of chloride was removed using an L/S of 2 l / kg with 5 minute extraction times. After the second stage of extraction 95% of the chlorides present in Ash II were removed. For Ash I all chlorides were removed at the end of the second step using an L/S = 5. However, owing to the fact that this experimental regime involved the major consumption of water and that the total chloride content of Ash I is much lower than that of Ash II, the use of an L/S = 2 with a two step extraction of 5 minutes will be sufficient to take away most of the chlorides and allow the use of this ash in building materials. Longer extraction times at L/S = 2 are no more effective than the shorter times.

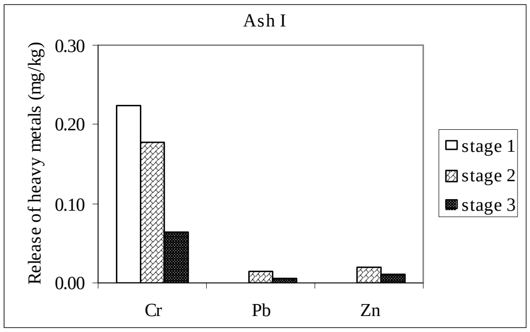
Both ashes generated hydrogen during extraction (in a greater amount for Ash I), corroborating the presence of metallic aluminium, as stated by other authors (Aubert et al., 2004, Chan et al., 2000). This evolution of hydrogen must be further evaluated before MSWI fly ash can be considered for use in concrete.

Sulphates were not removed to the same extent as the chlorides. However, combining the results for sulphate solubilization with those obtained for the chlorides it was concluded that the best extraction regime occurs at L/S = 2 with two extraction times of 5 minutes.

Table 3. Results of extraction experiments

Extraction condition		Ash I			Ash II		
		Final pH	SO_3(%)	Cl (%)	Final pH	SO_3 (%)	Cl (%)
L/S = 2	15 min	12.6	5	65	11.9	2	54
L/S = 2	5 min	12.5	3	45	12.0	2	51
	5 min	12.7	6	83	12.2	7	95
	5 min	12.8	10	97	12.6	12	105
L/S = 5	5 min	12.7	4	66	12.4	8	51
	5 min	12.9	7	100	12.6	14	81

The presence of Cd, Cr, Cu, Pb and Zn found in the extracts during the multistage treatment with a L/S = 2 was also evaluated (Fig. 3). The quantity of Cd and Cu released was insignificant and is not shown in Figure 3. Generally, the release of Cr and Zn from the MSWI fly ashes decreases from stage to stage. For Pb a different behaviour was observed as there was an increase in removal during the second washing step. In relation to the total content it was found that there was only a small release in heavy metals, with Cr being the most leachable metal in Ash I, (0.06%), and Pb in Ash 2, (0.15%).



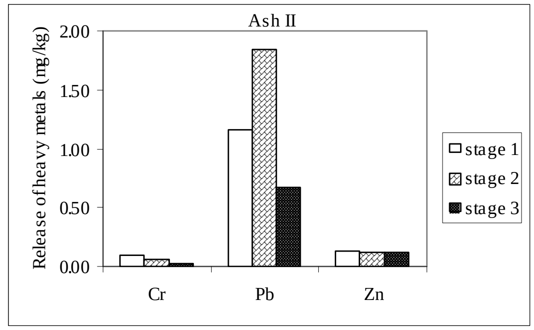


Figure 3. Release of heavy metals in the multistage treatment at L/S = 2

From the results of the XRD analysis of the treated fly ashes following the multistage treatment with L/S=2 it was also possible to see the evolution of chlorides due to the extraction treatment (Fig. 2). In the washed Ash I sample the disappearance of the peaks of halite and sylvite (the chloride crystalline forms) could be observed. In the Ash II sample there is also a significant change in the pattern of the diffractogram; the disappearance of the peaks of halite, sylvite and calcium chloride hydroxide confirm the efficient removal of chlorides. Other peaks from the XRD analysis indicate a reduction in their intensities and there were also some new peaks detected (i.e. ettringite).

4 CONCLUSIONS

This study has shown differences in the chemical and mineralogical composition of Ash I and Ash II which must be further investigated in order to confirm the use of MSWI fly ashes in the construction sector. According to the regulatory thresholds of the Council Decision 2003/33/CE, the two untreated fly ashes are classified as hazardous wastes. The high chloride level in the leachate of Ash I is the only reason for this classification.

Remarkably, the removal of chlorides in fly ashes is achieved by the simple process of washing the residues with distilled water, at the pH of the wastes. The best compromise between low water/time consumption and chloride removal was a two step washing at L/S of 2 l / kg using 5 minute extraction times; 83% of chlorides from Ash I and 95% of chlorides from Ash II are removed.

Additional research is being carried out on the leaching behaviour of treated fly ashes in order to define possible percentages of incorporation for both ashes in concrete.

5 ACKNOWLEDGMENTS

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REFERENCES

Abbas, Z., et al. 2003. Release of salts from municipal solid waste combustion residues. *Waste Management,* 23 (4): 291-305.

Al-Rawas, A. A., et al. 2005. Use of incinerator ash as a replacement for cement and sand in cement mortars. *Building and Environment,* 40 (9): 1261-1266.
Alba, N., et al. 2001. Stabilization/solidification of MSW incineration residues from facilities with different air pollution control systems. Durability of matrices versus carbonation. *Waste Management,* 21 (4): 313-323.
Aubert, J. E., et al. 2006. Utilization of municipal solid waste incineration (MSWI) fly ash in blended cement: Part 1: Processing and characterization of MSWI fly ash. *Journal of Hazardous Materials,* 136 (3): 624-631.
Aubert, J. E., et al. 2004. Metallic aluminum in MSWI fly ash: quantification and influence on the properties of cement-based products. *Waste Management,* 24 (6): 589-596.
Batchelor, B. 2006. Overview of waste stabilization with cement. *Waste Management,* 26 (7): 689-698.
Chan, C. C. Y., et al. 2000. The behaviour of Al in MSW incinerator fly ash during thermal treatment. *Journal of Hazardous Materials,* 76 (1): 103-111.
Chandler A. J., E. T. T., Hartlén J., Hjelmar O., Kosson D. S., Sawell S. E., van der Sloot H. A, Vehlow J., 1997. *Municipal Solid Waste Incinerator Residues,* Amsterdam, Elsevier Science.
Chimenos, J. M., et al. 2005. Optimizing the APC residue washing process to minimize the release of chloride and heavy metals. *Waste Management,* 25 (7): 686-693.
Collivignarelli, C. & Sorlini, S. 2002. Reuse of municipal solid wastes incineration fly ashes in concrete mixtures. *Waste Management,* 22 909-912.
De Casa, G., et al. 2007. Physical-mechanical and environmental properties of sintered municipal incinerator fly ash. *Waste Management,* 27 (2): 238-247.
Derie, R. 1996. A new way to stabilize fly ash from municipal incinerators. *Waste Management,* 16 (8): 711-716.
Eurostat 2005. Waste Generated and Treated in Europe – Data 1995-2003. *Theme Environment and Energy,* EUROSTAT, S. O. O. T. E. C. L. http://epp.eurostat.ec.europa.eu/.
Ferreira, C., et al. 2005. Effect of major constituents of MSW fly ash during electrodyalitic remediation of heavy metals. *Separation Science and Technology,* 40 2007-2019.
Geysen, D., et al. 2004. Comparison of immobilisation of air pollution control residues with cement and with silica. *Journal of Hazardous Materials,* 107 (3): 131-143.
Hong, K.-J., et al. 2000. Extraction of heavy metals from MSW incinerator fly ashes by chelating agents. *Journal of Hazardous Materials,* 75 (1): 57-73.
Huang, W.-J. & Chu, S.-C. 2003. A study on the cementlike properties of municipal waste incineration ashes. *Cement and Concrete Research,* 33 (11): 1795-1799.
Juric, B., et al. 2006. Utilization of municipal solid waste bottom ash and recycled aggregate in concrete. *Waste Management,* 26 (12): 1436-1442.
Lin, K.-L., et al. 2003. The Reuse of Municipal Solid Waste Incinerator Fly Ash Slag as a Cement Substitute. *Resources Conservation & Recycling,* 39: 315-324.
Malviya, R. & Chaudhary, R. 2006. Factors affecting hazardous waste solidification/stabilization: A review. *Journal of Hazardous Materials,* 137 (1): 267-276.
Mangialardi, T. 2001. Sintering of MSW fly ash for reuse as a concrete aggregate. *Journal of Hazardous Materials,* 87 (1-3): 225-239.
Qiao, X. C., et al. 2007. Investigation into the stabilization/solidification performance of Portland cement through cement clinker phases. *Journal of Hazardous Materials,* 139 (2): 238-243.
Reijnders, L. 2007. Cleaner phosphogypsum, coal combustion ashes and waste incineration ashes for application in building materials: A review. *Building and Environment,* 42 (2): 1036-1042.
Sakai, S.-i. & Hiraoka, M. 2000. Municipal solid waste incinerator residue recycling by thermal processes. *Waste Management,* 20 (2-3): 249-258.
Wainwright, P. J., Creswell, D J F. 2000. Synthetic aggregates from waste using an innovative rotary kiln. *WASCON 2000 - Proceedings Int. Conference Science & Engineering of Recycling for Environmental Protection*.
Wan, X., et al. 2006. A study on the chemical and mineralogical characterization of MSWI fly ash using a sequential extraction procedure. *Journal of Hazardous Materials,* 134 (1-3): 197-201.
Wilewska-Bien, M., et al. in press. Treatment process for MSW combustion fly ash laboratory and pilot plant experiments. *Waste Management,* In Press, Corrected Proof.

Eco-friendly construction materials using gypsum and industrial wastes

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ABSTRACT: The sustainable construction greatly depends on the use of alternative products, such as industrial wastes. This paper reports the development of new composite materials based on gypsum incorporating granulated cork, a by-product of cork industry, cellulose fibres from waste paper and recycled used tyre fibres. The composite material developed is intended to be used as boards for non structural elements of construction, such as dry walls and ceilings. This research work studied the characteristics of the gypsum binder commercially available and its properties, as well as composite boards. In order to enhance the water resistance and mechanical properties of the composites several mineral additions were evaluated. Physical and mechanical properties of the developed boards were studied. Finally, fibre reinforced composites using waste materials were produced and analysed. Conditions and procedures of production were also studied using a pressure curing method in order to improve further the performance of the boards.

1 INTRODUCTION

The sustainable world's economic growth and people's life improvement greatly depend on the use of alternative products in the architecture and construction, such as industrial wastes. These materials conventionally have been referred to as "green materials".

Cork (bark of the plant Quercus Suber L), a substance largely produced in Portugal, is a material whose characteristics are of considerable interest for the construction industry. It is regarded as a strategic material with enormous potential due to its reduced density, elasticity, compressibility, waterproofing, vibration absorption, thermal and acoustic insulation efficiency (Gil 2005 & Hernández-Olivares, 1999).

Currently the world's annual paper consumption is in the order of 370 million tonnes (www.walesenvtrust.org.uk, 2007). Recycling of paper is generally considered to be the priority and best practicable environmental option. The cellulose is a self agglutinant material, when saturated and pressed link together its own particles. This material can provide a good binding agent for the used materials.

Tyres are produced at 250 million units each year in Europe (www.specialchem4polymers.com, 2004) and nowadays, there are recycling companies that proceed to shredding of used tyres, obtaining separated materials such as crumbed rubber particles, steel fibres and textile fibres from the tyre beads and reinforcement. The textile fibres have applications for use in insulation materials or as fibre reinforcing in concrete products (www.wastebook.org, 2007). In this research work the recycled used tyres textile fibres were used with the objective of providing reinforcement for gypsum composites.

The gypsum is a large used material in building construction by its diverse applications. However it is up till now a material with a lack of know-how, mainly at research level. The European production of extracted gypsum attained 21milions in 1996. The European industry has 220 factories that produce gypsum products and employ, direct or indirectly, more than 400 000 persons. In Portugal it have been produced about 500 000 ton of gypsum for each ear since 2000 (www.wastebook.org, 2007). The building sector consumes about 95% of total gypsum produced. It is calculated that about 80 to 90% of finishing interior work and partition walls in buildings are made of gypsum products, such as plaster and card gypsum. According to those thermal and acoustical properties, these products contribute significantly for the comfort of millions of persons. Having an extraordinary resistance to fire, the gypsum products contribute for the buildings security, particularly in public buildings.

One of the biggest deficiencies of gypsum as construction material is the low resistance to water. Although, actually, this aspect can be partially solved by adding to the gypsum some compounds based on silicones or other polymers, namely in gypsum card boards. This way, gypsum can be submitted to humid conditions, but even so do not permit utilization in external environments because of its low resistance to long direct contact with water.

The main purpose of this research work was to develop gypsum boards with enhanced mechanical and water resistance. To these boards were also incorporated wastes to turn them more lightweight and sustainable. It was intended to show that the manufactory of these boards for not structural construction elements is possible, for example, for internal and external coverings, dry walls and ceiling. For this, it was carried out the characterization and improvement of gypsum as construction material, turning it more resistant to water action. After, applications of this enhanced gypsum based material were studied focused on the mixture preparation, methods of casting and its corresponding physical performance.

2 MATERIALS

For this study four commercial available types of gypsum were selected: one plaster gypsum, recommended for manual application, one for projection, one for finishing and one escayola gypsum. According to the developed chemical analysis of these gypsums it was verified that the manual plaster and escayola gypsum presented a higher purity than the finishing plaster one by the higher calcium sulphate content (CaSO4). For this reason, these plasters were selected as the main materials for this research work. In terms of particle dimensions it was seen at laboratory tests (EN 13279-2, 2004) that the escayola gypsum have a bigger fineness. In terms of moisture content the tests (NP 319, 1963), shows that the plaster gypsum have a moisture of 1,05% and the escayola of 1,32%. It was also determined through tests (NP 318, 1963) the water/gypsum ratio necessary for a conventional plaster and the minimal gypsum content essential for hydration. The obtained water/gypsum ratio necessary for a conventional plaster was 0,52 and for the minimal hydratation reached 0,20.

The used granulated cork is a by-product of a Portuguese industry containing diverse parts of cork with different particle sizes. The density is 384,5 kg/m^3 and the bulk density is 160,0 kg/m^3.

The cellulose fibres or paper pulp was made in the laboratory joining waste office paper, triturated in a mix machine, and water. The water content was the necessary for the mixture with gypsum.

The used tyre fibres are a material obtained by a recycling company of used tyres shredding. These fibres are generally composed by wires and cords (70% polyester, 15% nylon, 15% glass) and some rubber residues.

The water absorption tests were realized according to the Portuguese standard, NP 762, 1969. For developed mixtures cured under pressure it was added a mineral retarder to extend the time of curing.

3 METHODOLOGY AND RESULTS

3.1 *Incorporation of cellulose, granulated cork and tyre fibres on gypsum plasters*

It was produced four different plasters with a constant water/gypsum relation of 0,7 with the plaster for finishing. One was made without any addiction (mixture G), one with cellulose fibres (mixture G/Paper), one with granulated cork (mixture G/Cork) and the other with tyre fibres (mixture G/ Tyre fibres – see figure 1). These samples were tested for compressive strength at dry and saturated after immersion conditions (Comp Dry and Comp Moist), to evaluate the lost of resistance during water contact. Flexural (Flex) strength and water absorption by immersion were also tested. The samples were cured at room temperature until 7 days and maintained at 40ºC, to stabilize the moisture amount, and the immersion was realized until two hours at room temperature.


Figure 1 – Gypsum plasters with cellulose fibres, granulated cork and tyre fibres

Analysing the obtained results it can be seen that the cellulose fibres addiction slightly improves the flexural strength and maintains the compressive strength, even in dry or moisture conditions samples (see figure 2). However the additions of cork or tyre fibres decrease the compressive resistances. At flexural strength the tyre fibres have a similar behaviour to the cellulose. For both addictions more ductile behaviour was verified during the mechanical tests. Figure 3 shows a reduction of 15% of water absorption on reinforced mixtures with cork or paper. For other side, with the addition of tyre fibres it was verified a small increase of water absorption.

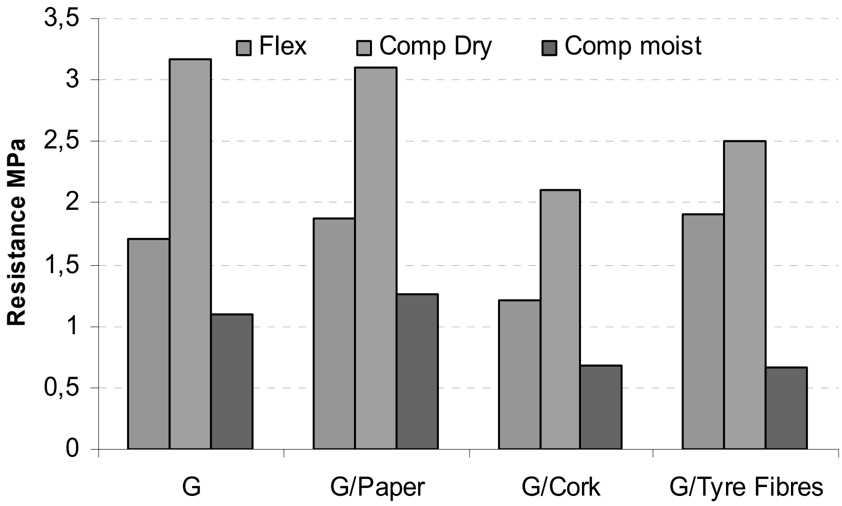

Figure 2 – Compare of plasters with paper, cork and tyre fibres

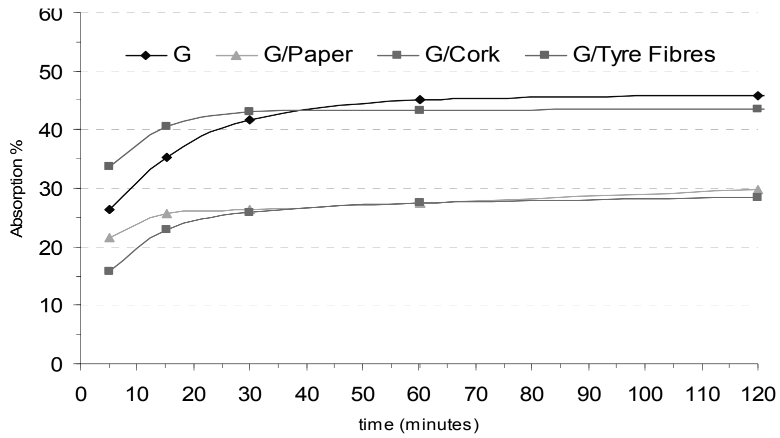

Figure 3 – Absorption of gypsum plasters

3.2 *Reducing water absorption by pressure curing*

A tested method for reducing the water absorption was by pressure curing of the gypsum based mixture. With this procedure it was possible to minimize the voids content and enables a reduction in the amount of water necessary to the mixture. This way, one can produce a much more compact mixture and, consequently, enhance significantly its performance. In this stage it was prepared a low consistence mixture joining plaster gypsum to only 20% of water (in mass). That corresponds to the minimal experimental determined value needed for hydration. Using a manual hydraulic press cylindrical samples were produced under a pressure of about 40,0 Psi (275,8 kPa). These samples were made at two different temperatures (room temperature, 25ºC, and 50ºC) and both were maintained after casting at room temperature until 7 days. For the tests the samples were maintained at 40ºC to stabilize the moisture content. After this the samples were submitted to compressive and water absorption tests by immersion until 2 hours. The saturated samples were also submitted to compressive tests.

Observing figure 4 one can compare the compressive strength results obtained in these pressed gypsum based mixtures made with the others selected plasters available on Portuguese market. As one can see a considerable increase on the compressive strength on the dry samples of pressed gypsum (legend on graphics as Press25º and Press50º), mainly at 50ºC, was attained. On the other way, the moist samples show a small increase in compressive strength.

In figure 5 it is possible to observe the water absorption test results obtained on pressed and un-pressed samples (pressed gypsum, plaster and commercial card gypsum board commercial designated as water resistant WR and in figure 5 as card gypsum WR). These results demonstrated the greatly favourable effect of pressed curing, responsible for a decrease in water absorption of about 40%. Comparing the pressed gypsum with the commercial available card gypsum tested, the pressed one maintains the values and the absorption of card gypsum continue to increase along the time.

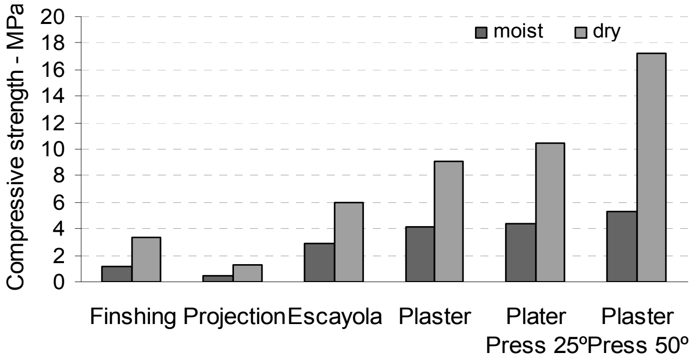

Figure 4 – Compare of plasters /pressed gypsum

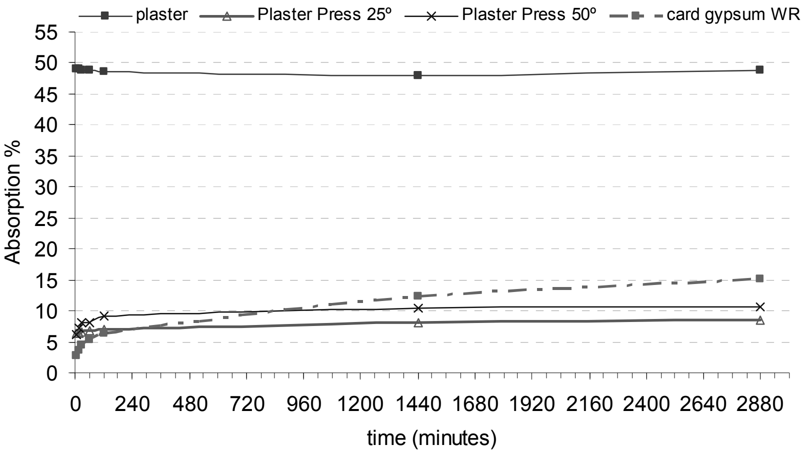

Figure 5 – Compare of pressed/plaster/card board gypsums

3.3 *Incorporation of cellulose, granulated cork and tyre fibres on pressed gypsum boards*

Once the pressure curing reveals to be very promising, it was adopted to the producing of gypsum boards. For the development of these boards it was necessary, at a first stage, to make them without any addiction to obtain the better process of manufacture and to achieve the adequate cohesion and finish. These boards were prepared with a metallic mould of 200x200 mm^2, filled with the fresh mixture made with a water/gypsum ratio of 0,20 and incorporating 0,3% (of gypsum mass) of mineral retarder. The boards were submitted to a pressure of 87,0 Psi (600,0 kPa) during 10 minutes. The boards were removed from the mould at the day after the casting and conserved subjected to 40ºC for curing and drying during 7 days. These have the designation P0 in Table 1 and figure 6.

As the same way, the boards with granulated cork and/or cellulose fibres or paper pulp were prepared following the same methodology of mix, casting, pressure and curing conditions (P1a until P4b). Six mixtures were prepared: two introducing granulated cork (2,5 % and 5 % of the mass of gypsum), two with paper pulp (3 % of the mass of gypsum) and the referred cork content (see Table 1); two with tyre fibres (2,5 % of the mass of gypsum) and the cork content; and other two mixtures with tyre fibres and paper pulp (2,5 % of the mass of gypsum and 3% of paper) and the cork content.

Table 1 – Material Percentages of boards (in mass of gypsum)

Board	Cork %	Paper %	Tyre %	Kg/m3
P0	–	–	–	1531,863
P1a	2,5	–	–	1460,39
P1b	5,0	–	–	1269,36
P2a	2,5	3,0	–	1168,939
P2b	5,0	3,0	–	1321,123
P3a	2,5	–	2,5	1281,439
P3b	5,0	–	2,5	996,0474
P4a	2,5	3,0	2,5	1311,23
P4b	5,0	3,0	2,5	1198,939

The next figures show the final appearance of the developed boards and the texture correspondent at near the real scale (see figures 6 to 8). Figure 6 show the simple board and incorporation of granulated cork and tyre fibres, figure 7 shows the incorporation of granulated cork and paper pulp in pressed gypsum-based boards.

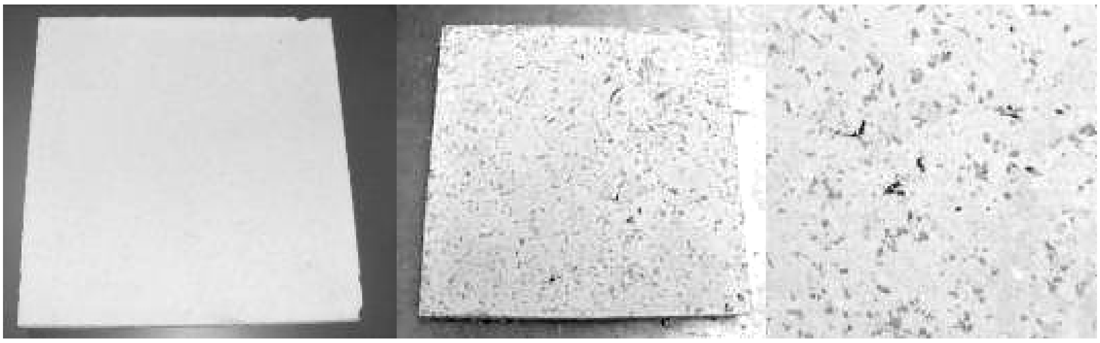

Figure 6 – Board of pressed gypsum P0 and board with cork and tyre fibres P4a and is texture

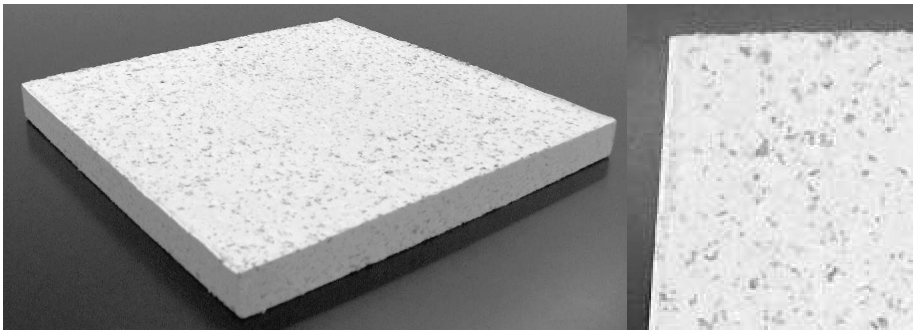

Figure 7 and 8 – Board of pressed gypsum with paper and cork and is texture P2a

These boards were submitted to flexural tests at 7 days of curing to evaluate their mechanical behaviour. By observing figure 8 it is possible to conclude that the mixtures flexural strength diminish with an increase of incorporated waste content, either for cork granules, paper and tyre fibres. Although, the paper fibre reinforcement on the mixture made with the greater cork content (P2b) reduces significantly the difference of resistances, showing the same behaviour in the paper reinforcement with the tyre fibres (P4a and P4b). This happened because the cellulose fibres behaved as a link between cork and gypsum turning the material more compact. The two materials work together as an adequate complement turning the boards more ductile than P0 (see figure 9).

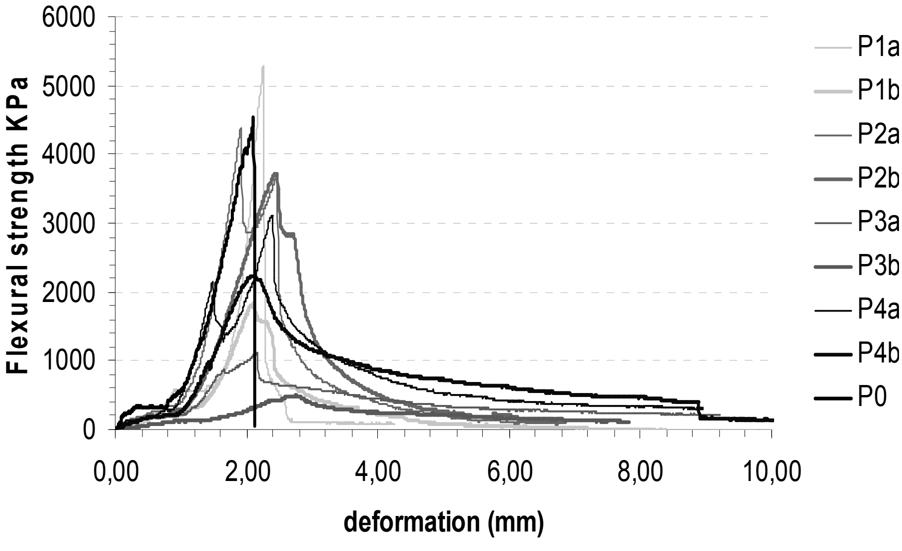

Figure 8 – Flexural behaviour of pressed gypsum

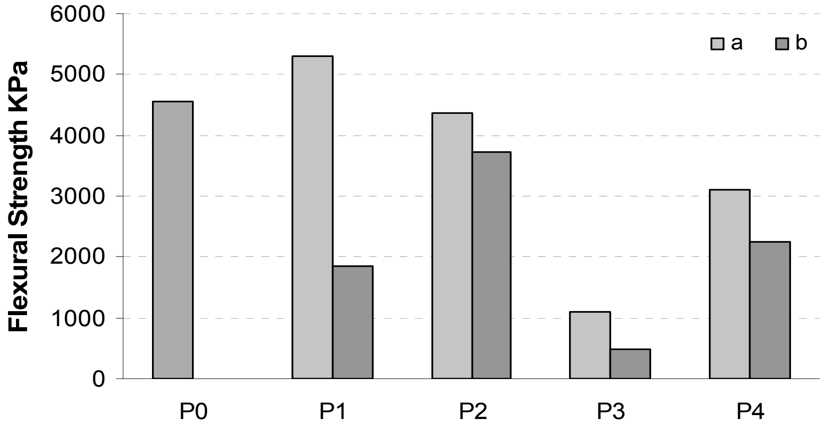

Figure 9 – gypsum/cork and cork/paper

4 CONCLUSIONS

According to the obtained results in the tested boards one can conclude that the incorporation of granulated cork or tyre fibres on plaster gypsum and pressed gypsum seems to be possible but reduces their mechanical performance. However these disadvantages can be compensated when compared with sustainable profit, density reduction and improvement of the conventional gypsum board in terms of thermal and acoustical behaviour (properties to be tested with the continuity of this research work).

This research work shows that it is possible to reduce significantly the water absorption by immersion, permitting an external application of these gypsum boards.

The addition of cellulose fibres can improve the flexural behaviour allowing higher cork contents with less reduction on resistances. Furthermore, this addition offers a better cohesion and finishing appearance when applied on pressed gypsum boards.

As well, it was verified the possibility of manufacture non structural construction elements, for example, internal and external coverings, dry walls or ceiling. These are new applications for the waste materials mentioned, turning the boards more environmental friendly, and promoting a new possibility for use gypsum in the external environments.

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5 REFERENCES

Gil, L. "Cortiça: da Produção à Aplicação", Ed. Câmara Municipal do Seixal – Ecomuseu Municipal do Seixal, 2005.

Hernández-Olivares, F., M.R. Bollati, M. del Rio, B. Parga-Landa. Development of cork/gypsum composites for building applications, Ed. Construction and Building Materials 13_179-186. www.elsevier.com, 1999.

www.specialchem4polymers.com, Tyre recycling, 2004.

www.walesenvtrust.org.uk, Tyres – Technologies; Paper and Card 2007.

www.wastebook.org, Rubber and tyres, 2007.

Concrete produced using crushed bricks as aggregate

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ABSTRACT: This paper presents the results of a research program carried out at University of Aveiro, Portugal to evaluate the properties of concrete made with crushed bricks and tiles. Two types of brick and one type of tile were investigated. These materials were crushed in order to obtain a usable aggregate. The properties investigated were the workability and the density of fresh concrete, and the compressive strength, tensile splitting strength, modulus of elasticity and stress strain behavior of hardened concrete. Compressive strength was measured at 7, 14, 28 and 90 days. Different replacement ratios were investigated as well as different water/cement ratios. The results of concrete produced with recycled aggregates were compared with a reference concrete produced with natural limestone aggregates currently used in Portugal. The results that were observed seemed to indicate that ceramic residuals could be used as partial replacement of natural aggregates in concrete. The type and the manufacturing process of bricks seem to influence the behavior of concrete. The resulting strength of concrete with bricks indicates the possibility of using this type of concrete in different precast applications.

1 INTRODUCTION

The sustainable construction concept was created a few years ago due to the growing concern about the future of our planet. In fact the everlasting increasing amount of wastes daily produced by industries and families demand urgent measures to reduce the amount of produced wastes and to find viable ways of recycling for those produced. Construction industry, in particular, is a huge waste producer and natural resource consumer, with recent estimates indicating that almost half of the wastes of industrialised countries have their origin in construction and demolition wastes (CDW). Simultaneously with the increasing of CDW, there is also a growing concern with the natural resource consumption, in the case of construction industry, mainly with natural aggregates that are rapidly diminishing. Estimates for the natural aggregate consumption in European Union indicate 6 to 8 tons per habitant, being only inferior to the water utilization. Impacts to the environment can be minimized by finding a way to reuse the products/materials when they reach their lifetime, which ensures only minimal impacts to environment, or alternatively, by extending their lifetime, thus improving their durability and reducing resource consumption. If both things can be done at the same time, an optimal environmental performance is attained.

Environmental constrains of stone pits, such as noise, dust, vibrations, considerable impact on the countryside, besides the consumption of a non-renewable material tend to considerably limit their exploitation. Consequently, alternative materials such as CDW as well as other industries by-products are increasingly being tested and used as environmental sustainable natural aggregates substitutes.

Ceramic materials are largely used in Portugal, both as bricks and tiles. Consequently, big quantities of wastes are produced simultaneously by the brick and tile manufacturers and by the construction industry. Most of the wasted of the manufacturers is already incorporated as raw material for new ceramic materials. Nevertheless, part of these wastes and those produced by the construction industry are placed in landfills.

Concrete is a material that is often seen as a potential place for wastes, because of its composite nature (a binder, water and aggregates) and because it is widely used, which means that if a waste could be used in concrete, then certainly large quantities of the waste material are crecycled. Regardless of several studies in this field, such as those from Poon et al. (2002), Khalafand e DeVenny (2004a e 2004b) Brito et al. (2005), there are some questions regarding the behaviour of concrete produced with ceramic wastes as aggregate. This uncertainty is basically related with heterogeneity of wastes, different compositions, reduced strength of crushed brick aggregates, lamellar shape of aggregates and so on.

The aim of this work is to investigate the effect of the replacement of natural coarse aggregate by two types of crushed bricks.

2 MATERIALS

All the materials used in this study were commonly available in the central region of Portugal where University of Aveiro is located. The cement used was ordinary Type II 32.5 Portland cement complying with NP EN 197-1:2001 (IPQ, 2001). Natural sand and calcareous coarse aggregates were used. Coarse aggregates were divided into two groups; one in the range 5-10 mm and the other in the range 20-25 mm (see Figure 1). Sieve analysis of all types of aggregates is shown in Table 1.

Recycled aggregates were ceramic bricks, from two local industries, that were crushed to obtain suitable sizes for using in concrete. As can be seen from Table 1, the final grading, of both types of crushed bricks was very similar. Photos of the two types of bricks after crushing are presented in Figure 2.

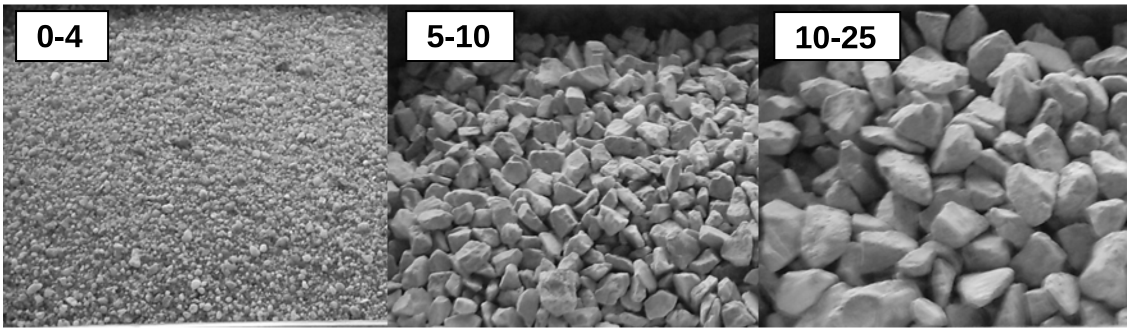

Figure 1. Natural aggregates used in this study.

Table 1. Sieve analysis of aggregates (NP EN 932-1:2000, IPQ 2000).

Sieve [mm]	Sand	Coarse Aggregate		Brick A	Brick B
		5-10	10-25		
31.5	100.0	100.0	100.0	100.0	100.0
16,0	100.0	100.0	84.0	100.0	100.0
8.0	100.0	78.0	2.1	99.0	99.0
4.0	100.0	1.9	0.2	39.5	46.2
2.0	84.4	0.29	0.18	6.53	11.5
1.0	53.5	0.29	0.17	2.55	3.05
0.50	22.7	0.17	0.16	1.67	1.04
0.250	5.7	0.13	0.15	1.33	0.67
0.125	1.8	0.12	0.12	1.13	0.55

Compressive strength of bricks before crushing was determined according to NP 80:1960 (IPQ 1960) and the results were 1.70 MPa for brick A and 2.55 MPa for brick B. the oven temperature at which bricks were made was, according to manufacture data, 850 to 870 ºC and 800 to 850 ºC for bricks A and B, respectively.

Figure 2. Crushed bricks.

Mechanical strength of aggregates was measured using NP 1039:1974 (IPQ 1974). This test was performed by placing an amount of aggregates in a cylindrical shape to which a pre-determined stress was applied. The results measure the amount of material transformed into powder. The results, presented in Table 2, showed that, as expected, the natural aggregate is better than recycled bricks and that brick B is better than brick A. This result in is agreement with that obtained for compression of bricks.

Table 2. Physical properties of aggregates.

Property		Standard	Units	Natural			Recycled	
				Sand	5-10	10-25	Brick A	Brick B
Crushing strength		NP 1039	%		21.7		30.8	27.3
Water absorption		NP EN 1097-6	%	0.79	1.33	1.07	15.81	18.91
Shape index		NP EN 933-4	%	-	13	7	30	16
Density	Saturated	NP EN 1097-6	kg/m^3	2813	2670	2652	2146	2233
	Dry			2791	2641	2617	1805	1928

Density tests were performed using NP EN 1097-6:2003 (IPQ 2003a). The results, presented in Table 2, showed that bricks had smaller density than natural aggregates which leads to lighter concretes. Water absorption tests indicate bricks absorb 16 to 18 times more water than natural aggregates. Additionally, the water absorption during the first minutes was measure to calculate the amount of water that brick aggregates consume during the mixing process. The results showed that 80 % of total absorption took place in the first 10 minutes.

Another property evaluated was the shape index that was measured using NP EN 933-4:2002 (IPQ 2002a). This test calculates the amount of particles that do not have a cubic shape, defined as the ratio between the maximum and minimum dimension being less than 3. Consequently, as the index increases, the amount of cubic particles decreases. The results, presented in Table 2, indicate that natural aggregate and brick A had similar shape index (13 and 16, respectively), while brick B had a substantially bigger shape index. Since the crushing process of the two bricks was exactly the same, the differences in results were caused by the nature of the brick itself.

3 METHODOLOGY

The study was designed to evaluate the effect of natural coarse aggregate by crushed bricks. Due to the nature of bricks and of the crushing process, the final grading of crushed bricks as showed in Table 1 implied that only the 5-10 mm coarse aggregate was replaced by recycled brick aggregates. Two percentages, 50 and 100 %, of natural aggregate were replaced by bricks. The replacement was carried out by volume. The weight of natural aggregate replaced was 15 and 30 % of the total weight of coarse aggregates. Additionally, two water/cement ratios, 0.45 and 0.5 by weight, were used that leaded to very different concrete workability. The amount of cement used was always 400 kg/m^3. Concrete mixes are summarised in Table 3.

Table 3. Summary of concrete mixes used in this study.

Materials	Concrete series name									
	NN45	NB45	NA45	BB45	AA45	NN50	NB50	NA50	BB50	AA50
Cement (kg/m^3)					400					
Water (kg/m^3)			180					200		
Sand (kg/m^3)			713					693		
5-10 ag. (kg/m^3)	398	199	199	---	---	386	193	193	---	---
10-25 ag. (kg/m^3)			748					727		
Brick A (kg/m^3)	---	136	---	293	---	---	133	---	285	---
Brick B (kg/m^3)	---	---	147	---	274	---	---	142	---	267
Weight (kg/m^3)	2440	2387	2378	2335	2316	2406	2355	2346	2304	2286
W/C (by wt.)			0.45					0.50		

In concrete composition, the aggregates were considered as saturated surface dried which means that the water absorbed by the aggregates was not included in the water/cement ratio (W/C). This procedure ensures that during the mixing process the workability of concrete is constant. Water saturation of aggregates was achieved by placing them in the mixer during 10 minutes. The water absorbed by the aggregates during this period of time should be added to the concrete mix.

As can be seen in Table 3, five different mixes were studied for each W/C ratio: a reference mix with natural aggregates, 2 mixes with 50 % of natural aggregates replaced by bricks (namely NA and NB, for brick A and B respectively) and 2 mixes with 100 % of the 5-10 mm natural aggregate replaced by crushed bricks (namely AA and BB).

4 RESULTS AND DISCUSSION

Several tests were performed on fresh and hardened concrete. Fresh concrete tests were workability (slump) and density. Hardened concrete properties measured were compressive and tensile strength and modulus of elasticity. Concrete curing was carried out with specimens immersed in water.

4.1 *Fresh concrete*

The results of fresh concrete properties are presented in Table 4. Slump was measured according to NP EN 12350-2:2002 (IPQ 2002b) the average slump for W/C = 0.45 was 5 cm and for W/C = 0.5 was 15 cm. regardless of the amount of natural aggregate replaced the workability was kept approximately constant for each W/C that proves the effectiveness of the adopted mixing procedure.

Table 4. Fresh properties of concrete

	Slump [cm]		Density [kg/m3]	
	w/c = 0.50	w/c = 0.45	w/c = 0.50	w/c = 0.45
NN	16	5	2420	2495
AA	13	2	2406	2468
NA	16	6	2392	2447
BB	15	5	2365	2395
NB	15	5	2335	2381

Density of fresh concrete was determined using NP EN 12350-6:2002 (IPQ 2002c). Results exhibit a clear and obvious reduction of density when recycled aggregates were used. Nevertheless, the reduction of density was only 5 and 6 % for concrete with W/C = 0.45 and 0.5, respectively.

4.2 *Hardened concrete*

Compressive strength of concrete was measured in 15 cm cubes according to NP EN 12390-3:2003 (IPQ 2003b) and the results are presented in Table 5. Results show that brick A always give smaller values than Brick B. Taking into consideration that compressive strength of brick B is higher, that it has better crushing strength and that its shape index is closer to that of natural aggregates these are predictable results.

Partial substitution with brick B shows no reduction of strength. For series NB45 a 10 % increase in strength at 90 days was observed. When all the aggregate 5-10 was replaced by crushed bricks, there is always a decrease of the compressive strength.

Table 5. Concrete compressive strength.

Series	Concrete age [days]			
	7	14	28	90
NN50	20.8	26.6	30.5	33.5
AA50	16.8	22.5	24.5	28.3
NA50	22.6	26.4	29.4	34.0
BB50	21.6	24.8	29.0	31.6
NB50	24.3	26.7	32.3	34.1
NN45	29.0	32.2	36.2	40.1
AA45	20.0	26.1	27.6	32.3
NA45	26.9	29.0	32.1	40.0
BB45	25.4	29.0	32.3	36.0
NB45	26.1	31.5	38.5	44.8

Tensile splitting strength of concrete was measured in 30 cm cylinders using NP EN 12390-6:2003 (IPQ 2003c) and the results are showed in Figure 3. Concrete was tested at 28 days. The conclusions are similar to those mentioned in compressive tests. A photo of a cylinder after testing is shown in Figure 4.

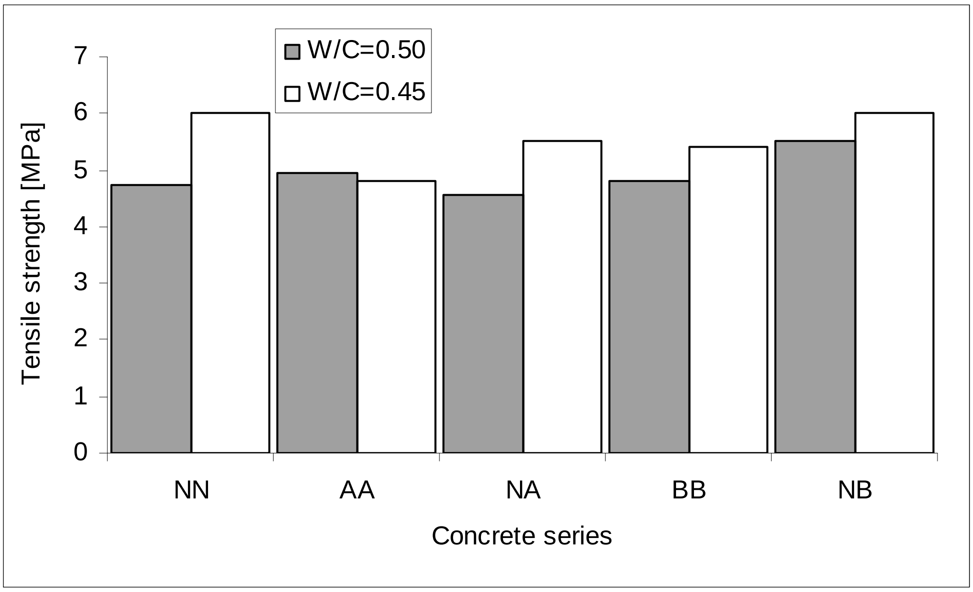

Figure 3. Tensile strength of concrete at 28 days.

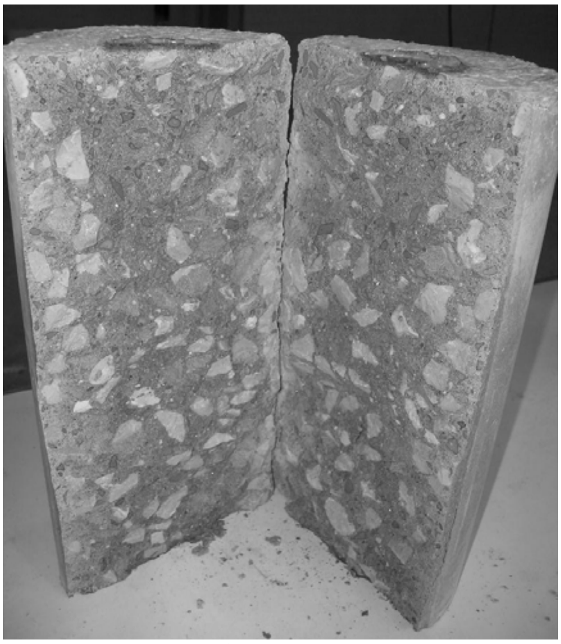

Figure 4. Modulus of elasticity at 28 days.

Modulus of elasticity of concrete was measured on 30 cm cylinders with strains being measured in the central 10 cm of the cylinder. Load was applied until approximately 30 % of ultimate load. The results are plotted in Figure 5 where it can be seen that there are no significant differences between concrete with recycled or natural aggegates.

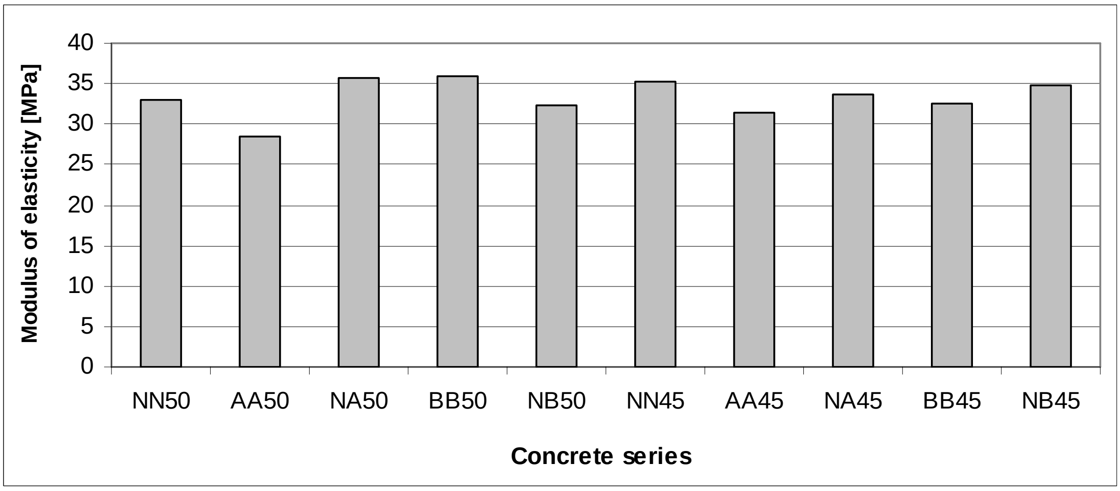

Figure 5. Modulus of elasticity at 28 days.

5 CONCLUSIONS

Results obtained indicate that crushed bricks could be used as natural aggregate substitute. When 15 % by weight of natural coarse aggregate was replaced by crushed bricks the strength and stiffness results were almost the same (in some cases they were actually slightly bigger). For 30 % of natural aggregate substitution, there is a reduction of concrete properties.

One of the most interesting results attained with concrete with crushed bricks is the strength development with time that leaded to strengths at 90 days bigger than those of reference concrete with natural aggregates. This could indicate that 28 day strength may not be a good indicator of strength for concrete with crushed bricks as aggregates.

The type of brick seemed to modify the results, at least to some extent. This means that some caution must be taken when crushed bricks are used as natural aggregate substitution, because in most of the cases the type, quality and origin of recycled bricks is unknown.

Another interesting facet that might be considered is the aesthetic possibilities that concrete produced using crushed bricks hold, that in some cases could be explored such in the case of urban equipment.

Regardless of all the work already performed in this area of research, there are still several aspects that must be studied and investigated. The results obtained so far from many researchers are quite challenging and promising.

6 ACKNOWLEDGEMENTS

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REFERENCES

Brito, J., Pereira, A.S. & Correia, J.R. (2005). Mechanical behaviour of non-structural concrete made with recycled ceramic aggregates. Cement and Concrete Composites, 27, 429–433, Elsevier.

IPQ (1960). NP 80:1960, Tijolos para alvenaria. Características e ensaios. Instituto Português da Qualidade.

IPQ (1974). NP 1039:1974, Determinação da resistência ao esmagamento. Instituto Português da Qualidade.

IPQ (2000). NP EN 932-1:2000, Ensaios da propriedades geométricas dos agregados, Parte 1, análise granulométrica, método da peneiração. Instituto Português da Qualidade.

IPQ (2001). NP EN 197-1:2001, Cimento. Parte 1: Composição, especificações e critérios de conformidade para cimentos correntes. Instituto Português da Qualidade.

IPQ (2002a). NP EN 933-4:2002, Ensaios das propriedades geométricas dos agregados, Parte 3, determinação da forma das partículas. Instituto Português da Qualidade.

IPQ (2002b). NP EN 12350-2:2002 Ensaios de betão fresco. Parte 2. Ensaio de abaixamento. Instituto Português da Qualidade.

IPQ (2002c). NP EN 12350-6:2002, Ensaios de betão fresco. Parte 6. Massa volúmica. Instituto Português da Qualidade.

IPQ (2003a). NP EN 1097-6:2003, Ensaios da propriedades mecânicas e físicas dos agregados, Parte 6, determinação da massa volúmica e da absorção de água. Instituto Português da Qualidade.

IPQ (2003b). NP EN 12390-3:2003. Ensaios do betão endurecido. Parte 3: resistência à compressão dos provetes de ensaio. Instituto Português da Qualidade.

IPQ (2003c). NP EN 12390-6:2003 Ensaios do betão endurecido. Parte 6: resistência à tracção por compressão de provetes. Instituto Português da Qualidade.

Khalafand, F.M., Devenny, A.S. (2004a). Performance of Brick Aggregate Concrete at High Temperatures. Journal of Materials in Civil Engineering, November/December, 556-565.

Khalafand, F.M., Devenny, A.S. (2004b) Recycling of Demolished Masonry Rubble as Coarse Aggregate in Concrete: Review. Journal of Materials in Civil Engineering, July/Augiust, 331-340.

Cachim, P., Pais, T. & Soares, J. (2005). Estudo das características de betão realizado com resíduos de tijolo. Relatório de trabalho, Universidade de Aveiro, Julho.

Poon, C.S., Kou, S.C. & L. Lam (2002). Use of recycled aggregates in molded concrete bricks and blocks. Construction and Building Materials, Elsevier 16, 281–289, 2002.

Glocal structural system in a seismic desert city

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ABSTRACT: Implementation of the new technology to answer an old problem requires an innovative approach. In this study, the aim was decreasing fatalities, caused by material fragmentation and collapsing, in an earthquake disaster. Thus, the main goal was an environmentally friendly way of materialization for reconstruction in a seismic desert circumstance. To achieve this goal, two main groups of effects on the construction, including desert environmental/ climate and earthquake resonance, were investigated. Although the study is globally applicable, as the work started with the main case study of Bam, a desert city that recently experienced a devastating earthquake. Therefore, we took the local regulations and technologies seriously into account. However, complexity of several aspects, affecting the system, made the study reasonable to be a subject for longer and broader study. We will discuss these aspects and their effects ending the discussion up to a suitable material in this paper.

1 INTRODUCTION

The Arctic sea ice area is at 70% of the amount found in 1870, and is shrinking rapidly (EPA, 2003). Forest cover is being lost at a rate of 10 million hectares per year (EPA, 2003). These kinds of negative influences on earth show that in the transiting to the modern age humanity lost the sustainable lifestyle, modern technology can highly improve and rehabilitate the sustainability in products and production technology. If the lifestyle is changed accordingly the earthly conditions are expected to improve. According to the book of WCED (1987) and the Brundtland-report (UN, 1987) the construction industry is responsible for about 10% of the total impact on this planet. Duijvenstein (2005) argued that striving for sustainability should not be restricted to design sustainable buildings but also be incorporated in the district and building in order to encourage sustainable living. There are several aspects to sustainable building and producing that have a relation with sustainability. One of these aspects is the conditions and available materials for building. In the best situation there is minimal transportation, minimal interference with local environment and no damage to nature. For this research the focus for finding a suitable material was on the rebuilding of Bam. Bam is a desert city located in the southeast of Iran. Bam was largely destroyed in December 2003 by an earthquake with a magnitude of 6.5 on the scale of Richter. It is estimated that Bam needs 40000 houses rebuild. For the rebuilding of this city a large amount of material and energy is needed and it would be beneficial if this rebuilding would happen as sustainable as possible. Furthermore because there is a serious risk that a new earthquake will occur within the next 50 years the buildings should be suitable for this condition. This paper concentrates on the research for finding a building material for the structure of houses that has both the best specifications for environmentally friendliness as well as constructional features for earthquake conditions.

2 APPROACH AND MATERIALS

Before it was possible to judge materials for their applicability in the restricted situation it was necessary to first decide on the relevant aspects for sustainability by studying the circumstances in Bam. This means not only describing the building conditions but also establishing the locally available materials and industry. This part of the study was done by literature research and visits to the local area. The second part of the research existed of material testing and further literature study. The test for the quality of desert sand for use in concrete was performed in the laboratory of the civil engineering at TU Delft for the typology and then chemical characteristics. Samples of 6 different specimens of fine and coarse aggregate, and clay were tested, based on NEN 5919 and 5941 (NEN, 1995). The agents of several samples found by these tests proved that the local materials have the quality, therefore, are applicable in the concrete mix (as it was supposed that desert sand is salty and is polluted, to be used in such a mix). The results of the mineral and chemical tests have been compared with the relevant literatures and interviewed with experts for the analysis and application.

3 ANALYSIS AND RESULTS OF THE STUDY OF THE LOCAL SITUATION

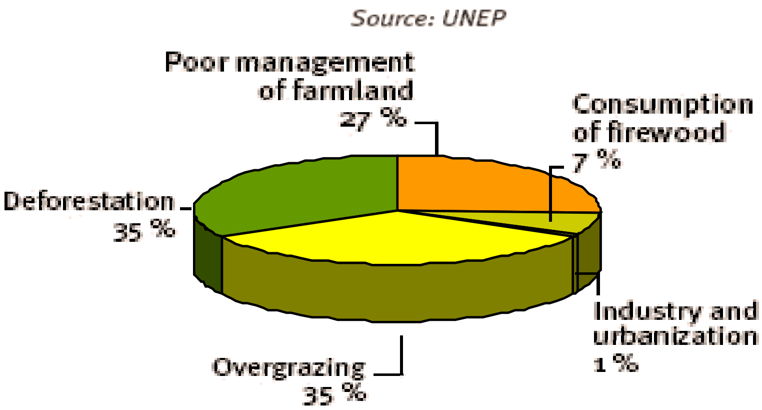
Although some of the processes and problems are global, this study focuses on Bam. In the end it will be interesting to test whether the solutions found for Bam and the methodology used is applicable globally. This is what is mending by the term Glocal that is in the title.

3.1 *Desert conditions*

The temperature changes over 24 hours are in desert areas known to be much higher than in vegetated areas the temperature difference (between the highest and lowest) exceeds 50 °C in Bam (IRIMO, 2006). This requires housing that can on the one hand withstand the temperature difference and on the other hand helps creating a comfortable climate inside the building. For sustainability, this leads to insulation specification as well as resistance to fast thermal transfer (cooling and heating).

Cities such as Bam, that are located in desert areas, are vulnerable to desertification. The diminishing or destruction of the biological potential of land which can ultimately lead to desert conditions is termed desertification (Pachauri et al, 1997). It is a kind of land degradation that occurs in dry (arid, semi-arid and dry sub-humid) areas. One important factor contributing to the acceleration of desertification and something that is occurring in all over the world is deforestation (kaya et al.1997). About 35% of the earth's land surface is at risk, and about 850 million people are estimated to be directly affected (MEA, 2005).The rate at which rain forests are disappearing all over the world is at 2 acres (0.8 hectare) per second. This amounts to 10 million acres per year for temperate zone forests (Kibert, 2005). In connection with carbon diffusion into the atmosphere (can be stored in tree mass) and also resulting the climate change, soil erosion and consequently land degradation. On a worldwide scale more than 2 billion tons of topsoil is lost annually and now, more than 12.5 billion acres is considered to be degraded (Kibert, 2005). 15% of the world's population inhabits dry lands, while 78.5 million live in areas that have recently undergone severe desertification (UNCCD, 2005). Figure.4.1. shows the land degradation on the earth due to different factors.

4.1. Causes of soil degradation



For the situation in Bam this means that the selected material should not decrease the quality of the land by extracting materials that are essential for that.

3.2 *Land and soil conditions*

Although Bam is located in the desert and there is little water on the surface, the evaporation on the soil level is not a problem. This is guaranteed by the existence of a large numbers of Quanat. Quanat is a water management system used to provide a reliable supply of water to human settlements or for irrigation in hot, arid and semi-arid climates (Figure 1).

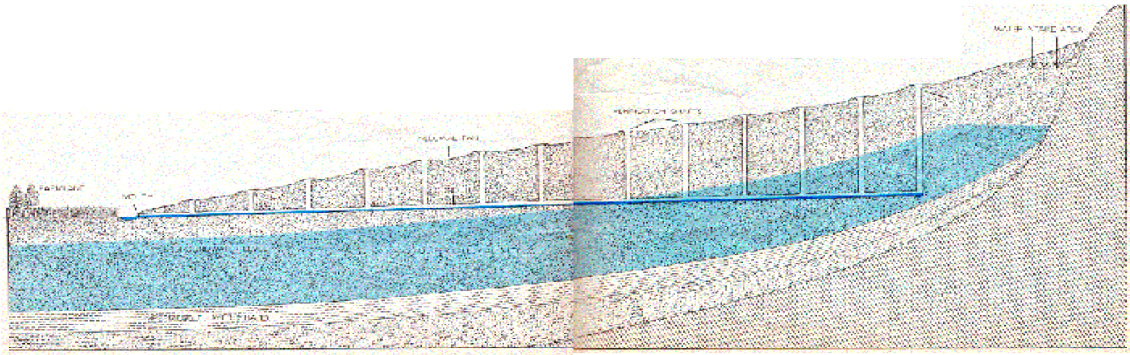


Figure.1. an ancient water system in the central desert of Iran called Quanat.

Because Bam is surrounded by mountains and the water coming from rain and snow is transported via the mountains into the deep layers of the land there is a constant supply of water for agricultural activities. The water in the deep layers is transported to the surface by the ancient system of Quanat. Bam is a town where most of the economy depends on agricultural exploitation. Bam is surrounded by date plantations and any changes to the quality of the top soil would seriously harm the economic condition of Bam. Any solution would need to consider the fact that Bam needs a sufficient area of arable land. Figure 2 shows the agricultural area of Bam that is now in use. Figure 3 shows the situation of it in economical activities and income of people.

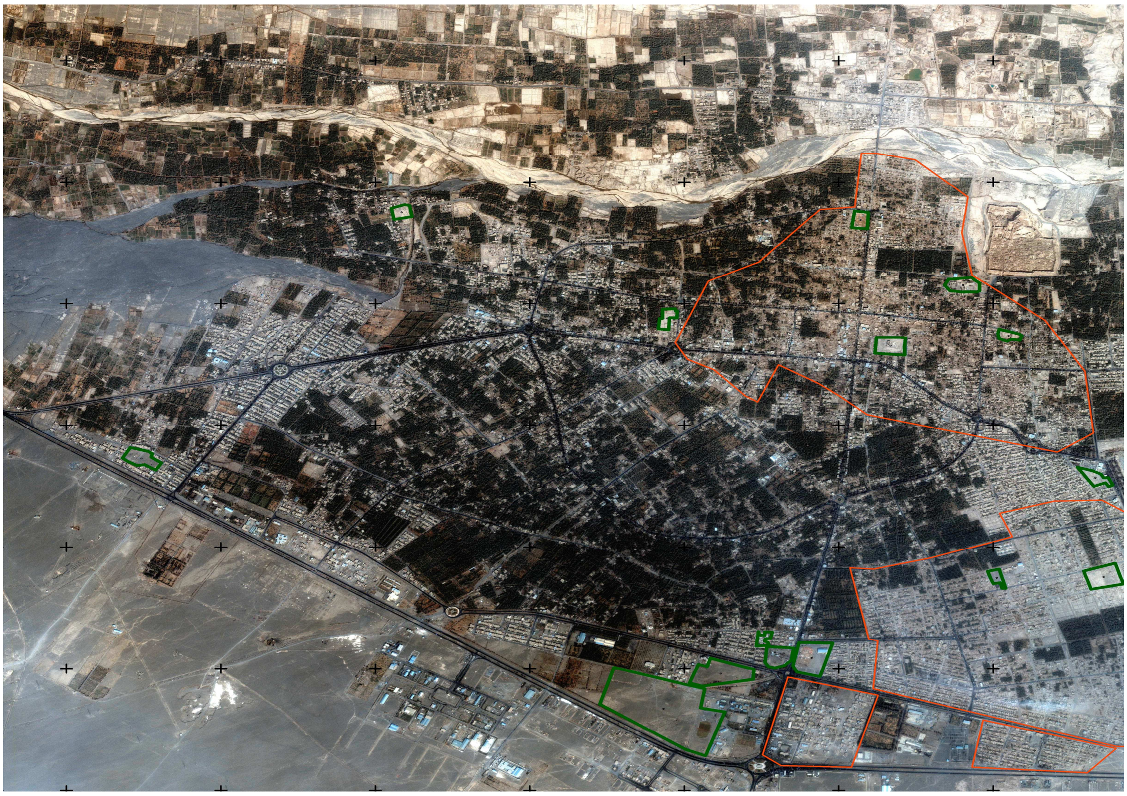
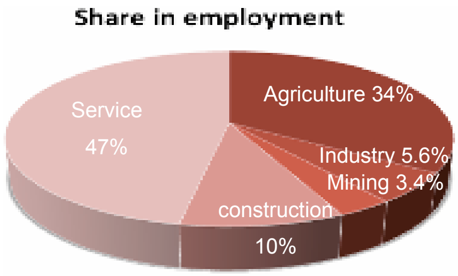


Figure 2 The greenery of the city of Bam (the agricultural area on the map)



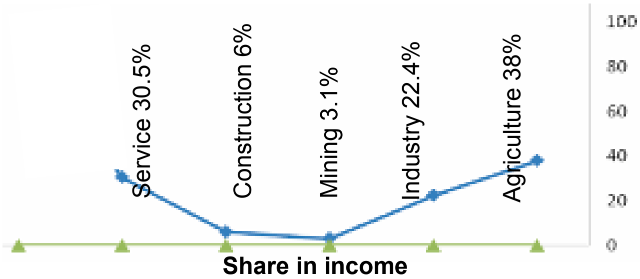


Figure 3 Share of the different sectors of the economy in Bam region (Based on the Report No.1, 2004, pp. 11 Statistical Center of Iran).

3.3 *Available materials*

As Bam is a typical desert city the area provides a lot of sand. Because some desert areas are known to be part of the bottom of ancient sees, it is possible that the sand around Bam is too salt to be suitable for building material.

A lot of the vernacular architecture is based on clay and bricks, which can be found and produced in the area. The adobe constructions were proven to be vulnerable to earthquake shocking and a lot of them were destroyed. Even the ancient citadel that is at least 2500 years old was seriously damaged by the last earthquake. Excavating the top soil to come to the clay would have a big impact on the quality of the arable land and is expected to have a negative effect on the available arable land and therefore on the economic situation in Bam.

3.4 *Earthquake conditions*

The earthquake occurred as result of activities of the Bam fault, which is located under the boundary of the city right on the edge of eastern side (Zare, 2004). In the earthquake December 2003 the main reason for the high level of fatality have been identified as lacking systemized construction and the quality of materials (Shahnoori, 2005).

By the site investigation the only structure that withstood the earthquake safely was found to be the main water tank which has a reinforced concrete construction. The adobe constructions were almost ruined and the brick structures were about 80-90% collapsed (Kimiro et al. 2005). In the table 1 the typology of damages regarding the materials use are demonstrated.

Table 1. The observed damages in the structures in site investigations (source: Kimiro et al, 2004)

No.	Principal Material	Degrees of Damage*	Note
No. 1	RC	C	14 spans (simple girders)
No. 2	RC	D	3 spans (simple girders)
No. 3	RC	D	7 spans (simple girders)
No. 1	RC	C	Reinforcing steel bar buckled
No. 1	Adobe	A	Total collapse
No. 1	Brick	A	Center pillar made of steel
No. 2	Adobe	A	Center pillar made of steel
No. 3	RC	B	Reinforcing steel bar buckled
No. 4	RC	C	Occurrence of crack on the pillar only

*Degree of damage: A= collapse, B= medium, C= Light, D= no damage

4 RESULTS OF THE MATERIAL TESTS

The main sources of minerals in the city is from the Poshterud river, in the northern boundary and Birdbrain River in KhajeAskar (a village very closed to the city). The quantity of the sources have been observed and interviewed and the quality have been taken to the Netherlands. The table number 2. demonstrates the final results of different tests on six samples of local materials. This is a summary, which out comes from the Dutch standards (Nederlandse Norm).

Table 2. The summary and final results of tests on local samples and comparison with the standards of NEN 5919 and NEN 5941

	Gravel + sand (fine)	Gravel + sand (bigger)
Fine material of organic origin NEN 5919	(Color B) good for the concrete	(Color A) good/better
Highly expanding clay minerals NEN 5941	Not so good and not so bad	

As it is going to be used in the reconstruction of a house the characteristics which are looked through are selective. However, based on the fact that has been proven in the last earthquake and further investigation, the reinforced concrete is basic for an appropriate material for the re-housing in such constrains. In which study continues for the improved version of a concrete composite. Therefore in the table 3 all the characteristics are chosen for a seismic desert house and all of the values are relative.

Table 3 The summary of the relative values of different versions of reinforced concrete

	Materials		
Characteristics*	Conventional concrete	Fiber reinforced concrete	PVA-ECC
Tensile strength	1	1	2
Compressive strength	2	3	4
Weight	1	1-2	3
Stiffness	2	2	3
Ductility	1	1-2	4
Problematic crack prevention	1	2	4
Environmental friendly	1	2	4
Durability	1	2	4

* 1= poor, 2=Acceptable, 3=Good, 4=Excellent

5 ANALYSIS MATERIAL SELECTION

From the literature and on site study it was concluded that both clay and brick had too much negative effects on the land and were poor for seismic conditions and constraints. That is why the second part of the research focused on concrete as structural building material for housing. The characteristics that are compared in table 3 were derived from the information gathered in the first research.

Because the characteristics mentioned in table 3 are equally important there was no need to add a valuation figures to them. This means that ECC qualifies best for rebuilding structures of houses in Bam based on table 3.

6 DISCUSSION

When people think of using environmentally friendly material in building they often come up with natural materials as clay and brick. This paper points out that because the excavation of clay causes so many negative side effects to the land and soil that it is hardly sustainable. Especially desert cities are at risk of desertification and deforestation, which is known to be one of the world's most threatening environmental effects (Kibert, 2005). Intensive use of clay would make Bam one of the regions that is damaged by human induces soil degradation and deforestation. As the most economical activity in the city is agriculture, using clay in such a large scale of construction (for more than 40000 houses and many of other buildings) is even more problematic. Besides, the use of concrete is technologically well evolved and it adheres to the local possibilities. Concrete is strong, stiff and durable which makes it very suitable for the reconstruction of a seismic desert city. It is flexible thus its quality increases further by combination with other materials.

Furthermore concrete is a well known material that is often used in earthquake risky areas. In Japan a lot of researchers seek for solutions that decrease the number of fatalities. However sustainability is not an issue with these researches and they are therefore not very applicable in Bam. This study proves that even though steel reinforced concrete might be found suitable for many earthquake areas it is probably not the most suitable material for Bam.
ECC is a relatively new material that is rather unknown in the building industry. The material was developed by Prof. Li more than 10 years ago. The idea behind the material was based on the experience with existing sorts of concrete such as the fiber reinforced concrete that was developed around 1970. One of the issues with concrete reinforced with steel bars that needed to be tackled was the cracking around the steel bars and on critical points in the structure. Markovic (2006) studied this matter and mentions two reasons why fiber reinforced concrete could work against this cracking. Firstly, the continuity and diameters of the steel bars with the tensile capacity and the stronger bond with concrete, and secondly the placement of the steel bars is being in the main tensile stresses direction, but fibers are randomly placed yet (Markovic, 2006).
For seismic conditions the ductility of concrete seems highly important. If a material is able to slightly follow the tremor movement it is likely that the material is far less sensitive to fragmentation and cracking. There are some researches that focus on workability and ductility in relation to fiber reinforced concrete (Groth, 2000; Kooiman, 2000; Markovic, 2006; Brite-Euram Project, 2002) but they did not come up with inclusive and reliable answers for such particular cases.

ECC (Engineered Cementitious Concrete) as studied in this research is mainly made of the same ingredients as the conventional concrete, minus the coarse aggregates, but doesn't have the disadvantages of the conventional concrete such as lack of durability, sustainability, failure under severe loading and resulting expenses for repair (Li, 2004). Additionally the amount of steel shear reinforcement can be drastically reduced since it remains highly ductile in shear (structure, 2007). The Michigan department of transportation used it to retrofit a section of the Groove street Bridge Deck over I-94, in the summer 2005 (Kahl, 2005). It has been used in a the School of Natural Resources and Environment Center for Sustainable Systems shows that in a 60 years service on a bridge deck the ECC is 37% cheaper, has 40% less energy consumption and creates 39% less CO2 pollution than the regular concrete. Besides, in the infrastructures structures such as high rise building it protects the FPR reinforced rebar from premature rupturing (Structure, 2006). Although practically it was not excessively used before, with its high quality will be a popular material soon. For example, it was adopted in the coupling beams of 27- story Glorio Roppongi High Rise in central Tokyo and the 41- story Nabeaure Tower in Yokohama by Kajima Corporation in Japan that is shown in figure 3 (Popular Mchanic, 2007).

Figure 3. Nabeaure Tower, Yokohama, Japan. Source: The Concrete Producer , 2006

To make the final solution for Bam even more sustainable it is essential that the design with ECC minimizes the life cycle costs of the building. A major goal of sustainability in cement-based building materials is to minimize the life cycle costs of buildings. The eco-cost can be lessened in more than one way, but according to Takao Tsumuro (2002) lengthening the lifecycle of a concrete construction building, improve insulation, efficient energy consumption all have a positive effect on the eco-costs. The differences in outside temperature between night and day are large and these have to be leveled for indoor climate to maintain an acceptable temperature inside the house. The building envelope is highly affected by heat and cold and the shell should not only be thermally insulated, but the thermal capacity should be kept up as well. Aside of influencing qualities such as strength, heat resistance and conductivity, the weight reduction can result in extensive cost reduction. With a lighter construction, the load bearing capacity can be reduced, thus constructing maybe easier. Additionally when it turns out the design cannot prevent the building from collapsing in a severe earthquake the clearance of debris in the area is eased. After the last earthquake there were approximately 12,000,000 tones of debris in the affected area, which took a long time to be salvaged and removed.

The study presented in this paper is part of a bigger research into the rebuilding of Bam. It was not a fundamental research by nature, but the intention was to find out whether ECC could be a suitable material for Bam. It is very well possible that there are other materials or types of concrete that are applicable in Bam, but it is also feasible that ECC is a good and sustainable material for a lot of other areas in the world. This would require further research but we expect that it will prove to be a reliable material for seismic desert cities all over the globe.

7 CONCLUSIONS

- Concrete is a sustainable material for rebuilding Bam.
- ECC is a good material for a building structure in a seismic area.
- Ductility is an essential characteristic for a building material in a seismic area.

8 ACKNOWLEDGEMENT

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REFERENCES

Brite-Euram Project BRPR- CT98-0813 (2002). *"Test and Design Methods for Steel Fibre Reinforced Concrete*", ISBN: 90-5682-358-2

Brundtland, 1987. *Our Common Future*, Report of UN World commission on

Environment and Development, Geneva, Switzerland, April 1987

Carson, R. 2002. *Silent Spring*. USA, Mariner Publisher ISBN-10: 0618249060.

Dobbelsteen, A.A.J.F. van den 2004. "*The Sustainable Office. An exploration of the potential for factor 20 environmental improvement of office accommodation*", Copie Sjop, Delft; ISBN 90-75221-02-9.

Duijvestein, K. 1995. "*Building and environment*" eco-build, Delft, HDJP180.

Illston, J. M. & Domone, P. L. J. 2002. *Construction materials*, Spon Press (Taylor & Francis group), New York, ISBN: 0-419-25860-4.

IRIMO, 2006. *Islamic Republic of Iran Meteorological Organization*

ISCE. 2004. *Iranian Society of Consulting Engineers*, Jan 4, 2004 to Jan 6, 2004.

Kibert, C. J. 2005. *Sustainable Construction: Green Building Design and Delivery*, John Wiley & Sons Inc, ISBN-10: 0471661139.

L&A Associates. ING, 2007. *Sanderson Project and annexations EIR IV Setting, Impacts, And mitigation…*, January 2007.

Liu, Y. 2002. *Defining digital architecture: 2001 Far East International Digital Architectural Design Award*. Birkhauser, Basel, 2002 ISBN: 3-7643-6891-8

MONPRF, 1996. *Ministry of Nature and Protection of Russian Federation*, 1996.

NEN 5941:1988 Aggregates for concrete - Determination of highly expanding clay minerals content

NEN 5919:1988 Aggregates for concrete - Determination of content of pollution by fine material of organic origin

Pachauri R.K. and Rajashree S. Kanetkar, 1997*Deforestation and desertification in developing countries*, *Environment, energy, and economy: Strategies for sustainability*, Edited by Yoichi Kaya and Keiichi Yokobori

Ray-Jones, A. ,2000. *Sustainable architecture in Japan : the green buildings of Nikken Sekkei*, Chichester, Wiley; ISBN: 0-471-86457-9

Shahnoori, S. ,2005. "*reconstruction in Bam with respect to seismic aspect",* International Conference of Kerpic5 Istanbul,

Tsumuro, T. 2002. Special Advisor to Obayashi Corporation

UNCCD, 2005. *Down to earth*, UNCCD secretariat.

World Resources Institute in collaboration with the United Nations Environment Programme (1992)

Waleraven, J. C. (2002). *"from High-performance to defined- performance concrete*, 6th International Symposium on High-Strength/High-Performance Concrete, Leipzig,

WCED. 1987. *'Our common future'*, World Commission on Environment and Development; Oxford, Oxford University Press, ISBN: 0-19-282080-X.

Webster. 2005. *Merriam Webster's Collegiate Dictionary*; eleventh edition, Merriam-Webster incorporated, USA, ISBN 10- 0-87779-814-9.

Zare, M. ,2004. *Processing result of the Bam Accelerogram obtained in 26/12/2003,*Special Page developed to the Bam Earthquake

Coolhouse: integrating very low energy geothermal cooling with sustainable construction

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ABSTRACT: A study of a very low energy alternative to air-conditioning applied within sustainable and energy efficient buildings, using simple but innovative construction techniques. The Coolhouse system passes fresh external air through ground tubes and into the building, exploiting the relatively constant below-ground temperature which remains at around the annual average air temperature, 14ºC in southern Portugal. This moderates the air temperature by either cooling or warming. The system is driven by a 0.17kW air-handling unit providing some 2.5kW of cooling energy in summer, and adding up to 9ºC to incoming ventilation air in winter. Coolhouse cools the adobe thermal mass of the well-insulated building construction, supported by passive considerations such as optimised solar shading and spaces that encourage stack effect natural ventilation. The adobe blocks are made on site, and have natural humidity control properties which work with Coolhouse to result in reductions of up to 30% Relative Humidity.

1 COOLHOUSE

Early EU estimates predicted 90m tonnes of CO2 annually from domestic air conditioning in Southern Europe by 2000, and this is now likely to have been greatly exceeded. The recent SIAM II study by the Gulbenkian Institute shows energy peaks are swinging from winter to summer in Portugal, largely due to the increased use of air conditioning. The Coolhouse system has been conceived, researched, developed and built to use ground cooling as a very low energy alternative to air-conditioning, and is now in everyday use in villas at Alma Verde in southern Portugal.

Alma Verde is an upper market commercially successful 36Ha residential new community which will have a destination spa and wellness centre at its core working to sustain both the community and local economic regeneration. At Alma Verde environmental issues are paramount in all aspects of design, where the use of sustainable and natural materials is optimised. The area experiences 3000 hours of sunshine annually, humidity reaches 95%RH and diurnal temperatures can range from 0ºC to 21ºC. The prevailing wind from the nearby Atlantic is consistently from the northwest.

Coolhouse combines both the geothermal cooling system and the passive design and construction of the building itself to achieve thermal comfort within a minimal carbon footprint. Strategies to support this aim begin at site level considering soft landscaping, orientation and building location.

2 SITE CONSIDERATIONS

Many thousands of trees and shrubs have been planted across the site as wind shelter belts, to alleviate the effects at ground level of the frequently strong prevailing breeze. These also provide wildlife corridors across the site linking to the surrounding wild countryside. Villa plots generally have a north-south orientation, with buildings being located to the north of the plot to provide both further wind shelter and south facing gardens. Timber trellis screens with dense climbing plants maintain privacy and streetscape where road access is from the south. The villas themselves are designed to optimise the solar contribution available from this north-south orientation.

3 PASSIVE ENVELOPE

3.1 *Passive design*

Careful design and construction of buildings can make a very considerable passive contribution to energy performance and comfort, working with active building services systems when necessary. The Coolhouse buildings are designed and built to use simple and sustainable low technologies, whose characteristics work to support the ground cooling system and make best use of the available coolth.

Solar gains are passively controlled by simple shading devices designed to prevent heat gains from the high summer sun but admit beneficial solar gains in winter, such as roof and roof terrace projections. Windows with unavoidable solar exposure have timber shutters and are set deep into the external wall for natural summer shading, where a solar reflective coating within the high specification glazing gives further passive protection. Generous north facing windows provide good levels of natural day lighting to the interior, and are free from solar gains.

3.2 *Thermal mass*

Heavy dense building materials have the capacity to store heat and cool by maintaining their temperature for long periods, and this thermal mass can serve as a radiant source of warmth or coolth. When thermal mass is well-insulated from outside ambient conditions, whether hot or cold, this capacity can be exploited to maintain thermal comfort internally. The Coolhouse villas are largely built from solid adobe blocks within an anti-seismic concrete frame and an adobe render finish, providing all-round thermal mass. The tiled beam and block concrete floors, and the well-insulated inverted roof design to roof terraces, all enclose the spaces they form with useful thermal mass. Typically, solar gains from the low winter sun warm the interior throughout the day, and much of this warmth is absorbed by the thermal mass of the adobe construction, raising its temperature. Good insulation and high performance glazing prevents the heat from dissipating to the cold air and winter night sky to the extent that mechanical heating systems are often not needed. In summer, the incoming cool air from the Coolhouse system keeps the thermal mass temperature down, maintaining a cool internal environment.

3.3 *Humidity moderation*

Adobe (sun baked clay) also has a less well-known characteristic in its ability to absorb airborne water vapour when humidity is high and release it when humidity falls. This helps to passively maintain significantly lower levels of Relative Humidity internally, avoiding the need for dehumidification. Water vapour from occupation activities such as showering and cooking are substantially removed at source by extract fans operated by presence detectors.

3.4 *Glazing*

Glazing specification plays a significant part in the Coolhouse low-energy strategy, with argon filled low-E solar reflective glasses, laminated for security, restricting both heat losses and gains with a manufacturer’s u-value of 1.1W/m2/ºC.

3.5 *Passive ventilation*

Good ventilation is also an important factor in achieving thermal comfort, particularly in hot climates. The design of internal spaces can passively promote air movement by the use of double height spaces or towers, encouraging a stack effect where warm air rises naturally and exhausts to outside. Incoming fresh Coolhouse air continually displaces warm internal air with cooled air when the system is running. As well as bringing in fresh cool air for ventilation, the thermal mass temperature is also kept low.

3.6 *Embodied energy*

Embodied energy, the energy used in winning raw materials, manufacturing processes, transport and so on, is also a significant energy expenditure that can passively contribute to reducing a building's carbon footprint. It has been suggested that by the time they are built many buildings have already cost in embodied energy 10-15% of the energy they will use during their entire lifetime of use and occupation. The Coolhouse villas are calculated to achieve a 15% reduction in their embodied energy compared with standard construction. Natural materials generally have low embodied energy. Timber in roof construction, window frames, staircases etc; natural stone door and window cills, worktops and wall and floor finishes; adobe blocks and render in the building construction all contribute to this saving. The sun-dried adobe blocks at Alma Verde are made on-site from local clay, hugely reducing firing and transport energy costs in addition to the other beneficial characteristics of adobe. Natural materials also have a 'feel-good factor' that people respond to and like to have around them.

4 BUILDING SYSTEM

4.1 *Adobe*

Anti-seismic regulations in Portugal require concrete frames for virtually all structures and because of this, walls are generally non-loadbearing infill panels which need to support little more than their own self-weight. This allows a composite external wall panel designed to meet environmental rather than structural design demands. The inner leaf is 115mm wide adobe block and mortar with 15-20mm adobe render internally, which effectively gives a monolithic thermally massive clay slab of 135mm width. Internal walls are also built from adobe block and render at either 270mm or 140mm width. A wall thickness of up to 500mm is usually required for adobe block construction to achieve structural strength by itself. It is important to maintain structural breathability for adobe construction, and laboratory tests were conducted at the University of Oporto to verify the vapour permeability of a variety of readily available types of paint. Water-based paints proved to be more breathable at significantly lower cost than their mineral paint equivalents, and provide the internal finish.

4.2 *External wall panels*

The adobe inner leaf is tied with stainless steel wall ties to the outer Tabicesa system terracotta 100mm block leaf. This block is used not only because it has better thermal performance than the standard Portuguese *tijolo* hollow terracotta block, but also due to its design. The ends of the blocks are fluted so that the blocks physically link together without the need for mortar at the vertical joints. Whilst this is designed for speed of construction, it also ensures breathability through this element of the external walls. There are two reasons for using a fired clay block in this location. Adobe has to be protected against prolonged exposure to water. The buildings are detailed so that the Tabicesa leaf forms part of a fully weatherproof building shell which can be completed before any adobe is installed internally. This sequence allows dry working conditions which protect the adobe from water damage if construction takes place during wet weather. The second reason lies in the use of the external insulation system which forms the outer layer of the wall composition.

4.3 *External Insulation*

In order to procure the manufacturer's guarantee for the external insulation system as part of this construction, accelerated ageing tests were undertaken at the STO laboratories in Germany to investigate the untried durability of the adhesive to an adobe surface. Whilst it did not fail in the laboratory, the manufacturer advised that a hard fired clay surface would remove any risk. External insulation is the ideal strategy for this form of construction, as the system is breathable and the very tough thin coat mesh and acrylic render finish is self-coloured, self-cleaning and flexible. This avoids the surface cracking associated with the standard cement render finish caused by the thermal shock of the diurnal temperature range, and eliminates the high maintenance demands of painted cement render. Thermal bridging is entirely avoided at openings and around the concrete frame, giving an overall u-value of 0.4 W/m2/ºC for the 300mm composite wall with 60mm of expanded polystyrene insulation. External insulation also covers the ground beam to 700mm below ground level to isolate the floor slab and sub-floor plenum from thermal bridging to outside ground temperatures.

4.4 *Roof*

At eaves level the external wall insulation extends above the concrete ring beam to seamlessly meet the insulation within the roof construction, completing the unbroken insulation envelope. Laminated timber rafters support the timber sandwich panel pitched roof deck, with its 80mm extruded polystyrene insulation core and factory-finished timber underside forming the ceiling to the rooms below. Finished with clay interlocking roof tiles on timber battens and a breathable waterproof membrane, the roof achieves a u-value of 0.31 W/m2/ºC resisting heat gains from the hot sun and losses to the cold clear winter sky.

All of these elements contribute to making full use of the cool incoming fresh ventilation air from the ground cooling system, which displaces warmer air to exhaust through permanent trickle ventilators in the timber window frames.

5 THE COOLHOUSE GEOTHERMAL SYSTEM

5.1 *Ground Cooling*

The temperature of the ground at 2m below the surface is believed to be within a degree or two of the annual average air temperature, which in southern Portugal is 14ºC, with some variations following from seasonal outside air temperature. If warm fresh external air is passed through the ground at this depth, it will lose its heat to the ground which serves as a heat sink. It may be useful if the ground is in shade or regularly watered as this helps keep the ground temperature cool and is likely to extend the hours that the system can operate. A period of perhaps ten hours per day is needed to allow the ground to dissipate its acquired warmth. Engineering calculations, CFD modelling and practical installation design for the given volume of building to be cooled optimised with two ground tubes each of 25m length. These are built from simple readily-available PVCu drainage components through which air is pulled by a 0.17kW variable speed air-handling unit within the house at the required velocity of 4m/sec. Fresh external air enters the system through a louvre on the cool north façade into a small chamber housing the air intakes. From here the ground tubes, which are laid with a fall of 1:60 (1.5%) to a sump at the deeper end to enable periodic cleaning, loop through the ground to terminate in the sound-insulated fan chamber. Passing through the fan and attenuator, the incoming air is ducted onward through a 315mm tube below ground, again from PVCu drainage components, to discharge into the fully damp-proofed sub-floor plenum. From here the cooled air passes directly through discrete and carefully sized slot outlets at skirting level at a velocity of 1.2 - 1.5m/sec into the space. The system continuously supplies low level cooling for up to 14 hours per day, cooling both the air and the thermal mass and reducing internal temperatures by as much as 12ºC below the outside air temperature.

5.2 *Ventilation pre-heat*

In winter the effect is reversed, as cold incoming air gains heat from the ground instead of losing heat. Ventilation air entering the system at 5ºC has been shown by monitoring to be leaving the ground tubes at 14ºC having gained 9ºC above outside air temperature, which is useful as ventilation pre-heat. This pre-warmed ventilation air is further warmed by the heating system as it enters the space. The heating system comprises a radiant heated skirting (rodapé) wet system around the perimeter of the rooms, driven by a 97% efficient modulating condensing gas boiler which also provides domestic hot water. With the fan speed reduced, incoming ventilation air passes slowly behind the heated skirting which warms the air further before it discharges through the outlet slots into the space. During the heating season the programmer can be set so that if the Coolhouse system is running it will override the heating system programme, and call for heat to be supplied to the heated skirting. This allows fresh internal air even with unpleasant external weather conditions.

This low temperature heated skirted system has other advantages over conventional radiators. The relatively high temperature at which radiators operate leads to hot spots in the thermal mass which can be uncomfortable, as well as causing fast-moving convected vortexes of rising hot air which distribute dust mites and airborne dust particles. Low temperature radiant skirting operates at a maximum of 180W/lin.m. The slowly rising continuous curtain of convected warm air not only evenly warms the thermal mass but also limits the airborne distribution of pollutants with obvious health benefits. It also gives the freedom to place furniture anywhere against the walls.

6 PERFORMANCE MONITORING

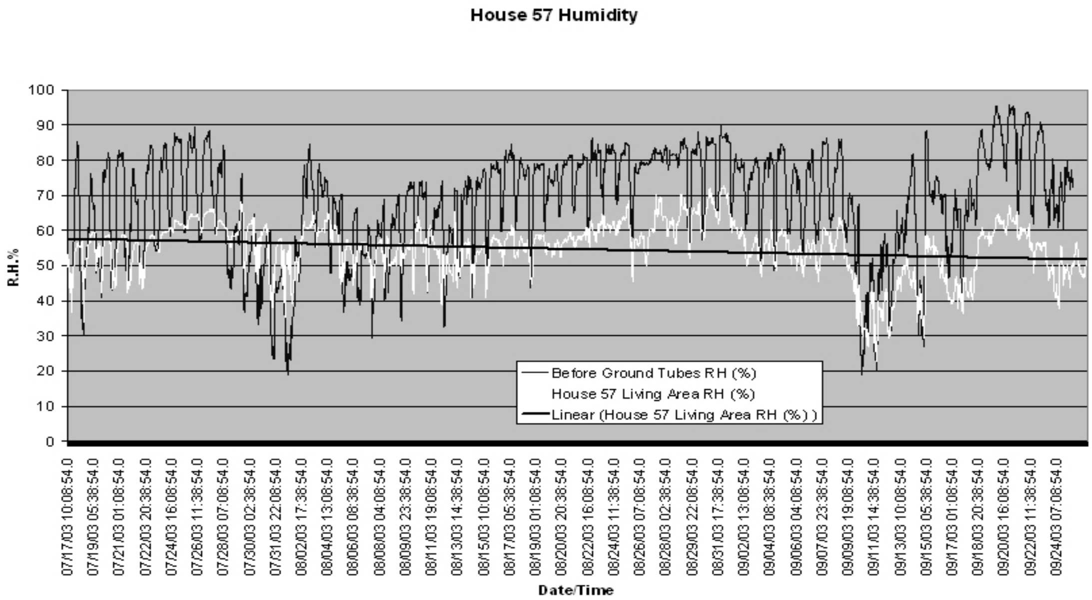
6.1 *Monitoring*

The integrated Coolhouse strategy was monitored for eight months during the exceptionally hot summer of 2003 by Faber Maunsell of London, conducting all monitoring processes according to standard international protocols. Using Hobo H8 data loggers, outside air temperatures were recorded on the shaded north façade along with ambient external Relative Humidity levels, whilst air temperatures and RH were also monitored at the entry and exit ends of the ground tubes. Air temperatures and Relative Humidity levels were also logged within the house, where data collected in the living areas tells of the real impact of the integrated Coolhouse strategy as it is experienced by occupants.

6.2 *Passive humidity moderation*

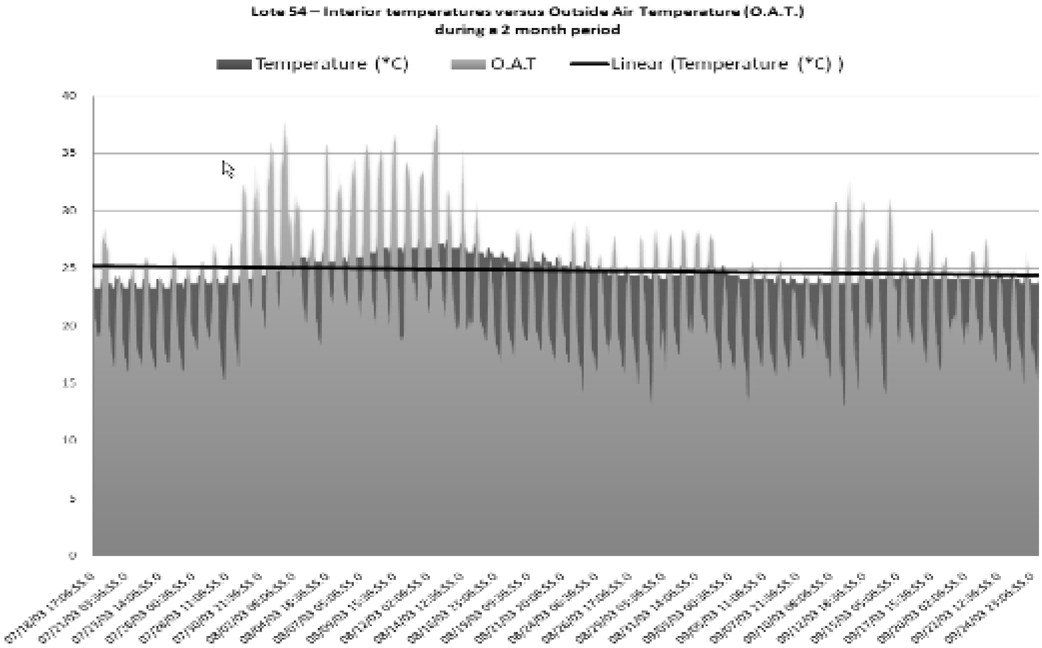
The capacity of adobe to entrain and release airborne water vapour has not been subject to much quantified research, but the beneficial results are striking. Monitoring of an occupied house shows that when humidity was running high at 95%RH outside, internal humidity was recorded at a maximum of 65%RH which is a massive reduction of 30%RH. This reading represents peak conditions; nevertheless reductions of over 20-25%RH are consistently recorded. The trend line shown on the monitoring graph represents to an extent an occupant’s experience of internal conditions. This trend line runs from about 58%RH falling over time to about 51%RH against more or less consistent outside conditions, and continues to fall reflecting the fact that the newly built house is drying out. This suggests that the final internal Relative Humidity will be consistent at no more than 50%RH. The RH band of 40-60%RH is considered to be the optimum for human health, and eliminates the respiratory disorders or dry eyes that can result if this range is exceeded. Unpleasant living conditions caused by condensation and black mould growth are prevalent in standard local construction in this climate and are very unhealthy, particularly for asthmatics. Damp is absorbed by bedding, clothing and paper, and mould appears on leather-wear, a problem which is commonly resolved by the use of electric dehumidifiers and wardrobe heaters. These problems are eliminated within the Coolhouse buildings, where salt remains dry in the salt cellar instead of absorbing water.

Whilst the mechanism by which this humidity reduction process takes place is not fully explained or researched, my belief is that two processes are working together. Internal airborne water vapour is drawn into the adobe element of the composite external wall due to the nature of the material. The mild pressurisation of the interior of the building caused by the incoming Coolhouse air forces the entrained water vapour to exfiltrate through the breathable external wall to dissipate outside the building. What is certain is that Relative Humidity is being very effectively reduced to healthy and comfortable levels.



6.3 *Internal air temperature reduction*

Monitoring of internal air temperatures over the very hot summer also confirmed the effectiveness of the Coolhouse ground cooling strategy, removing peaks of outside air temperatures and achieving an even air temperature throughout the year. The trend line for an unoccupied house stands consistently at 25ºC, where an occupied house predictably holds its temperature at a degree or so higher. In the hottest peak conditions, this represents an internal temperature reduction of 12ºC compared with the 38ºC recorded as the outside air temperature. Consistently stable and comfortable internal conditions are maintained regardless of conditions outside. This without doubt results from the combination of thermal mass with the Coolhouse ground cooled air, supported by the other passive measures designed into the buildings.



7 SUMMARY

The integrated Coolhouse system operates in a very different way to conventional air-conditioning, providing stable reduced temperature internal conditions through a constant supply of cool air. Unlike thermostatically-controlled air-conditioning which will supply blasts of cold air irrespective of outside conditions until its set point is reached, Coolhouse air maintains some relationship with outside air temperatures. This avoids the discomfort associated with the greater ΔT found with air-conditioning. The Monitoring Report confirms that the system is robust and may be operated in a number of different ways, such as long or short periods, night purging etc and still achieve very acceptable internal temperatures. It concludes that the Coolhouse technologies are very successful and provide high comfort levels for low energy consumption, and everyday use confirms occupants are more than satisfied with the system as a viable alternative to air-conditioning.

The Monitoring Report calculates to achieve the same environmental conditions, the use of split unit air-conditioning in the same three monitored houses would generate 15,200 kgs/CO2 compared with the 810 kgs/CO2 which the Coolhouse system generates.

This represents a 94% saving in CO2 emissions, with a payback of nine years for the cooling contribution only. As such, it has the potential to make a considerable impact on the CO2 emissions resulting from the increasing use of domestic air-conditioning in hot climates identified by the SIAM II study.

The environmental benefits of the Off-Site Manufacturing

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ABSTRACT: The contemporary orientations in design activity, in production offer and in building techniques is by now distant from the idea that such issues have to pass through an industrialized management and rigidly serial of building elements. The panorama of technological options underlines the presence of innovative construction products and systems - such as volumetric units, panellised frames, structural insulated panels - functional to the rapidity of the cycle of production and reduced employment of resources, easily adaptable to the variability of contextual situations, to assemble with dry techniques and able to guarantee the satisfaction of specific technological and environmental requirements. The use of increased potentialities of design and production processes has contributed to the development of innovative products and systems potentially able to ensure high functional and design quality standards and to offer a wide range of environmental benefits especially in terms of speed of construction and waste reduction.

To face the theme of prefabrication within sustainable architecture involves the need to investigate a wide series of aspects that caused deep changes in the building process: the orientations of design activity and of production offer, the adoption of techniques and construction practices, the modalities of buildings management. Environmental issue has in fact assumed an important role in directing the strategic choices in construction sector both at commercial level, both at normative level, and through a progressive rethinking of architecture design and its construction phase.

The concept of prefabrication has assumed during the years a less rigid meaning in comparison to the hypotheses assumed in the period of its theoretical formulation: we assisted in fact to the passage from “heavy” and closed systems, to products and systems – result of processes of *light* production – functional to the rapidity of the cycle of production and to lesser employment of resources, easily adaptable to the variability of demands of the market and contextual situations, to assemble with dry techniques and able to guarantee the satisfaction of specific technological and environmental requisites. The use of the increased potentialities of design and productive processes allowed the passage from an economy of scale to a scope economy, contributing to the development of morphologically similar products, but with different dimensions and performances. Therefore not numerous samples of a same type of product but a number, varying on demand, of different products from the same typological class.

The diffusion of prefabricated products and systems in industrialized countries appears rather variable: if in Scandinavia in fact around 80% of new houses is realized *off-site*, in the United States – despite the promotional efforts of various government agencies – the market is strongly dominated by traditional building processes (Kieran & Kimberlake 2003). In Japan few great corporations control the prefabrication market, with companies like Toyota that, with

Figure 1. Steel-frame housing construction method by Toyota Home. The company is developing new products which meet “Next generation energy-saving standards” and has been taking measures to reduce CO2 emissions at both the occupation stage and the production stage. In the graph the results of waste reduction measures at construction sites of prefabricated houses and goals (Toyota).

sophisticated IT driven production and assembly plants, is capable of producing thousands of housing units per year (Bottom, Gann, Groàk & Meikle 1996). Different firms, using CAD/CAM manufacturing capabilities, *Enterprise Resource Planning* strategies and software, and advanced building simulation capabilities into manufacturing processes, can produce high quality, high performance building products at relatively low cost.

Especially in countries like United Kingdom, Sweden, Germany and Japan, in the last years numerous research projects were finalized to investigate the possibilities of development of standardized production and employment of prefabricated products and systems in housebuilding. The research projects involved manufacturing firms, research institutes, universities, designers and building contractors and allowed to individualize numerous consequential advantages from the employment of advanced systems of production and to delineate the future scenarios of the *Off-Site Manufacturing* (OSM).

From the sustainability point of view, the advantages from the use of prefabricated products and systems are in fact related to a greater control of quality in the production phase, less waste of material in factory and on site, higher speed in the construction phase. The consequences include the improvement of profitability and productivity for contractors, the increase of guarantees on product final quality for buyers and consumers, the reduction of resources employment and of general investments finalized to the building construction, less impact on the environment during on site works.

Figure 2. Structural timber housing system. Precision-engineered wall and floor panels are fixed together before the roof is lifted on to the top (Space4).

In fact, according to the scheme of environmental evaluation by the European Program EuroHouse (Long 1999), are considered, among the consequential benefits from the employment of prefabricated systems:
- from 30 to 60% in the reduction of times on site through a more efficient coordination of the different construction packages;
- the reduction of 50% of water quantity in comparison to a traditional construction;
- 50 reduction% of the quantity of material utilized and produced by excavations;
- wider use of recycled materials (like timber, steel, aluminum, etc.);
- up to 80% in the reduction of waste materials during on site works;
- up to 60% in the reduction of CO_2 emissions and of annual energy consumes during building life cycle;
- possible reutilization and reuse of prefabricated elements.

The raising of prefabrication is mainly addressed (even if interesting niches of production remain in commercial, hotel and industrial sector) to the diffusion of structural building systems in the housing market. This tendency departs from the consideration that it is necessary to use industrialized components able to answer quickly to the variability of demand, fitting without conflicts in the market of the traditional contractors. Building systems must be able of mutual integration and be conceived and coordinated to be assembled to create not a single house model but different solutions and typologies, realizing buildings that are not formally and technologically determined by its use. The issues connected to these strategic objectives are:
- the research for every component of the maximum dimensional and finishing variability;
- the research of the maximum speed of construction with the wider quantity of dry assembly procedures;
- the minimization of the number of components;

- the use of *lean* production processes to reduce the incidence of stocks and to increase the product quality;
- the development of assembly procedures independent from atmospheric conditions;
- the research of minimum weight;
- the facilitation of maintenance operations.

With such premises, one of the most interesting challenges for the diffusion of OSM in housing building process concerns the overtaking of cultural barriers connected to standardization and prefabrication issues. Among the different actors of the building process, users and designers result particularly damaged by the errors made during the long history of prefabrication: errors that, at different scale, can be recognized in the majority of housing experiences in different countries. The carelessness of contractors in comparison to design reasons, the general low quality of the buildings, the abrupt fall of building performance with inevitable investments for the maintenance – in many cases uncertain and transitory – have contributed during the years to the abandonment of housing prefabricated systems and to privilege building solutions mostly known and controllable. Particularly, users recognize buildings realized with the traditional technologies more in conformity with the applications of reliability, resistance and duration in comparison to the prefabricated building systems (Craig, Laing, Edge 2000). At general level can be said that a typical tendency is to introduce in the market, close to the basic constructive system, more and more articulated series of special elements, or in any case integrated, that completed the offer of traditional products and systems, preserving therefore the possibility to continue to use materials management on site consolidated in the building tradition.

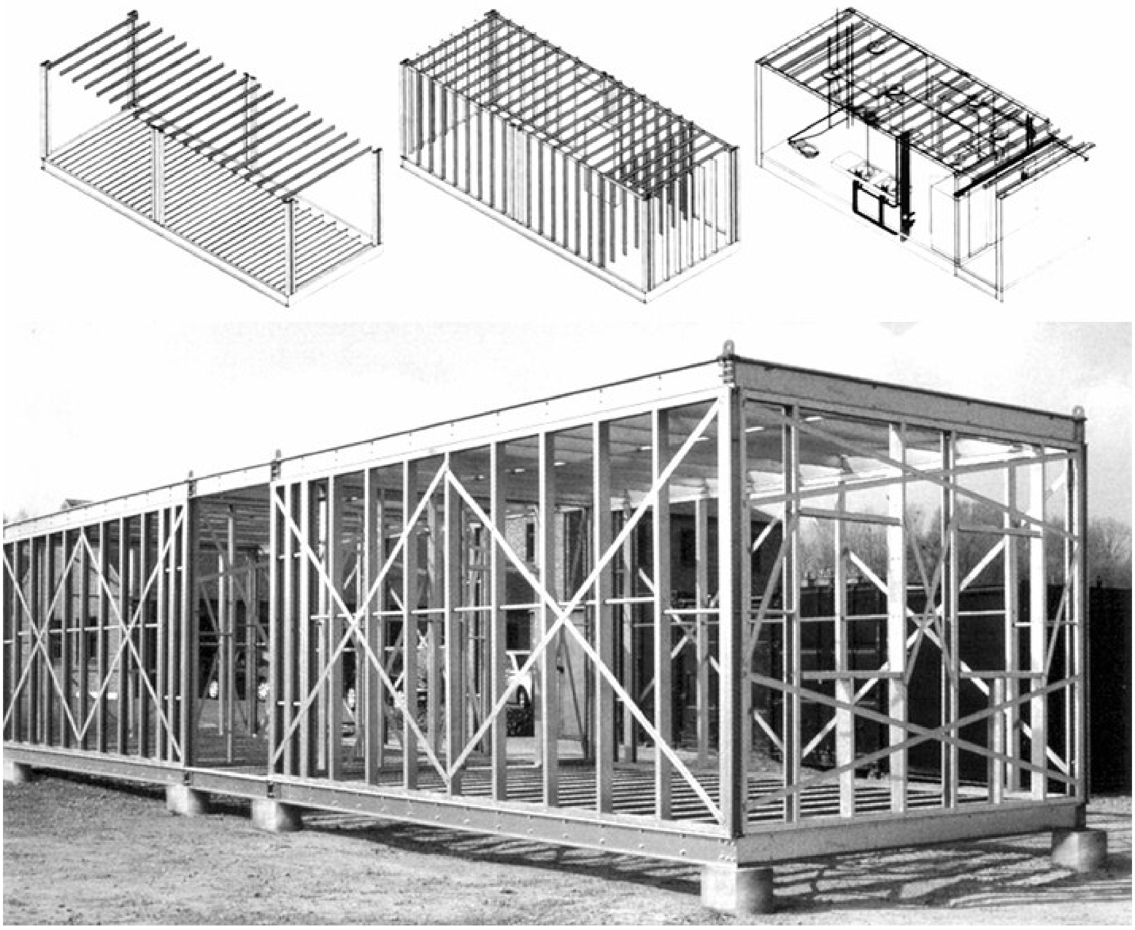

Figure 3. In Volumetric system the CFS braced units are completely prefabricated in the factory and can be delivered to site with all internal finishes, fixtures and fittings in place (Kingspan).

Not by chance some recent productive tendencies include not only the offer of building solutions with high level of prefabrication that can be completed with traditional materials and techniques, but also OSM systems like, for instance, monolithic brick panels that, thanks to its reassuring formal qualities, result particularly accepted by users.

In such point of view it is possible to individualize the tendency from public and private clients to ask for a wider use of OSM in housing interventions, both for building elements and for installation systems, supported by numerous research programs by manufacturing firms of materials and components, finalized to the improvement of the production processes and the increase of products performance. The prefabrication task of the last years can be seen in a series of housing realizations, some of which experimental, useful to verify formal and technological potentialities of the prefabricated systems (Arieff & Burkhart 2002; Birkbeck & Scoones 2005). Broadly publicized by the press in different countries, these realizations have seen the collaboration of users associations, local administrations, manufacturing industries, designers and contractors, succeeding to reach satisfactory results in commercial and design terms.

In the wide catalog of structural prefabricated systems available on the market result particularly interesting those with large scale elements, like façade panels, floor slabs, staircases, bathroom pods, etc., made in timber, steel or reinforced concrete. The trend to use large prefabricated elements sees the building manufactures proposing elements with high performances, low formal predetermination, light and dimensional flexibility, to assembly with easy operations. Such systems don't exclude besides the possibility to be completed with traditional techniques and materials, through an interesting process of contamination and integration of building solutions with different level of innovation.

The use of prefabricated structures allows besides to minimize waste production on site, that becomes the place where to assembly industrialized products and not a place where to *create* manufactured articles (with consequent extension of construction times, waste production and possible increase of errors).

As consequence of different researches and realizations of residential buildings in different countries, we assisted in the last years to a growing diffusion of structures conceived and designed to be realized with large dimension elements (panels or three-dimensional modules) created by the assemblage of horizontal and vertical elements. Vertical panels can be formed by a rigid closed cell insulation, as pressure injected CFC free polyurethane, incorporated among outer skins of aluminum, galvanized steel, concrete or Oriented Strand Board (like the *Structural Insulated Panel* - SIP), or from a frame of braced profiles in *Cold Formed Steel* (CFS), manufactured from roll formed galvanized steel strip with thickness between 1.2 to 2.4 mm. The use of steel seems to play a fundamental role in sustainability issue, particularly for the attributes shown in Table 1.

Table 1. Attributes of steel in sustainable construction (Widman 2005).

Usability	Steel construction is pre-fabricated in efficient factory processes with minimum use of resources, and enables long-span, high rise and flexible buildings
Speed	Steel structures are installed rapidly on site which reduces local disruption
Weight	Steel construction are light and therefore efficient on materials, energy, transports and emissions. The low weight also enables vertical extension and optional location
Waste	Steel construction is very material efficient, generating low amount of waste, and most of the waste is recycled
Performance	Steel is high performance, dimensionally accurate material, produced with modern computerized technology
Logistics	Steel structures are delivered to site “just in time” for nstallation and can be produced locally
Durability	Steel structures have long very design life and the high quality remains
Health	Steel construction is dry construction, low-emitting material, controlled and safe process and leads to high quality architecture
Recyclability	All steel can be recycled without quality losses and all steel has recycled content
Reusability	Steel buildings or components can be dismantled, upgraded, relocated or re-used

Figure 4. Application in Malmo (Sweden) of almost fully equipped modules in light gauge steel framing mounted in a framing system with steel columns to form multi storey residential buildings. The system provides cost-effective, environmentally sustainable dwellings of good quality and with short production time (Open House System).

In such point of view CFS members – light, easily-handled and with a wide range of shapes and dimensions – can be combined as Panel construction, Volumetric or Semi-volumetric system (Trebilcock 1994; Gorgolewski, Grubb, Lawson 2001). In the Panel construction wall panels, floor cassettes and roof trusses are prefabricated in a factory and later assembled on site. In the Volumetric system units are completely prefabricated in the factory and delivered to site with all internal finishes, fixtures and fittings in place. Units are stacked side by side, or craned one above the other, to form a stable finished structure, using the form resistance of the "wagons" and the dimensional precision reached by productive processes. In the Semi-volumetric "hybrid" solution Panel and Volumetric systems are used together.

The three-dimensional units are generally employed for those parts of the building – as bathrooms and kitchens – that require long time of realization and skilled labour. The different members of the systems are lifted and assembled among them using dry connection systems to reach, according to the different systems, from three to five floor height. In the Volumetric solution the main installations systems are directly incorporated in the factory inside the panels: on site must be made only the necessary connection among the different modules. Therefore the construction proceeds rapidly and not only guarantees the reduction of realization times (calculated around 60%), but also of the service life energy (25%), in comparison to more conventional construction procedures (Widman 2004).

The systems can be completed with the integration of different materials, products and techniques, also not necessarily from industrial source. It's possible in fact to realize on site some parts of the building – as the staircase-elevator tower – or to use dry assembly systems, as the different typologies of envelope with metal studwork substructure and external rainscreen.

The possibility to integrate the systems with different technologies is related with an aspect that makes reference to the recent innovations of the productive processes. The use of these systems doesn't condition in any way the architectonic outcome, thanks to possibilities offered in factories by versatile methods of production, able to vary on application some characteristics of the products, in times and costs comparable to those of series production. Through the use

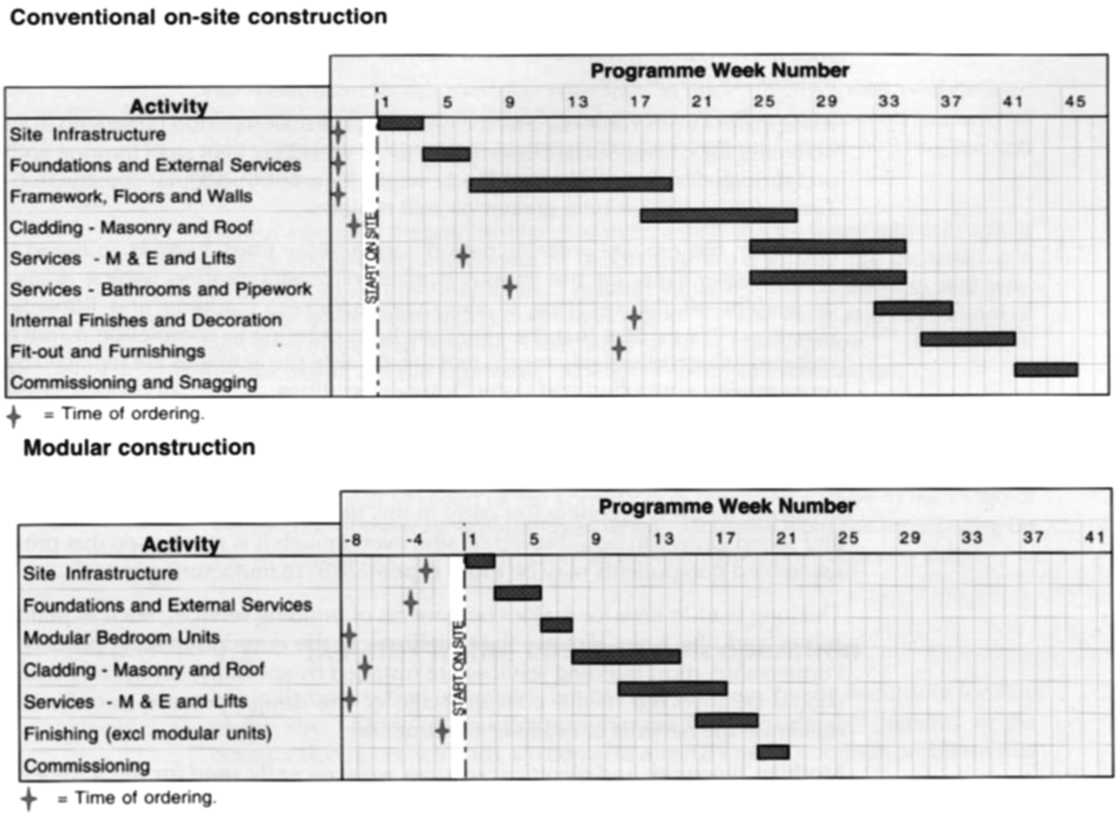

Figure 5. Comparison of procurement and construction process between on-site and modular construction for a typical medium-sized building (Gorgolewski, Grubb, Lawson 2001).

of light production models it is in fact possible to quickly modify the type of workmanship of the elements that compose the systems offering diversified configurations of the final product.

Even if the manufactures generally have the tendency to provide prefabricated elements with standard dimensions, in effect it is possible to produce numerous typologies of elements with notable borders of morphological, dimensional and technological variability.

The speed of construction, assured by the physical characteristics and by the assemblage modalities of the elements, permits also interventions in high density areas, minimizing the risks and the uneasiness on site and in neighboring zones, as for instance noise, dust, vibrations, etc. An aspect that influences in negative way the diffusion of the large element prefabricated systems is the equipment for the lifting. Usually habitants feel like an intrusion in their private life the use of big cranes and bulky lifting systems for building operations. Some contactors transport the prefabricated elements on trucks provided of small sized cranes to avoid the construction of fixed equipments and try to obviate the problem suspending the prefabricated members to the arms of the site equipments (generally excavators), using it as handling operator.

Building industry of prefabricated components tries therefore to orient itself toward a production in agreement with eco-compatibility issues, promoting the decrease of material and energy intensity of the production processes and reducing, at the same time, the use of non renewable resources. To such strategic finality are evident numerous points of contact between the innovative ways of industrial production and the sustainability goals. In fact, besides the design and the eco-compatible construction, it is important also to develop conditions of sustainability within the housing industrial production. In fact the investments of numerous manufacturers try to individualize the possibilities that industrial production offers for an advantageous relationship among environmental aspects and methodologies of improvement of production processes and products. Some modifications related to the structure of the

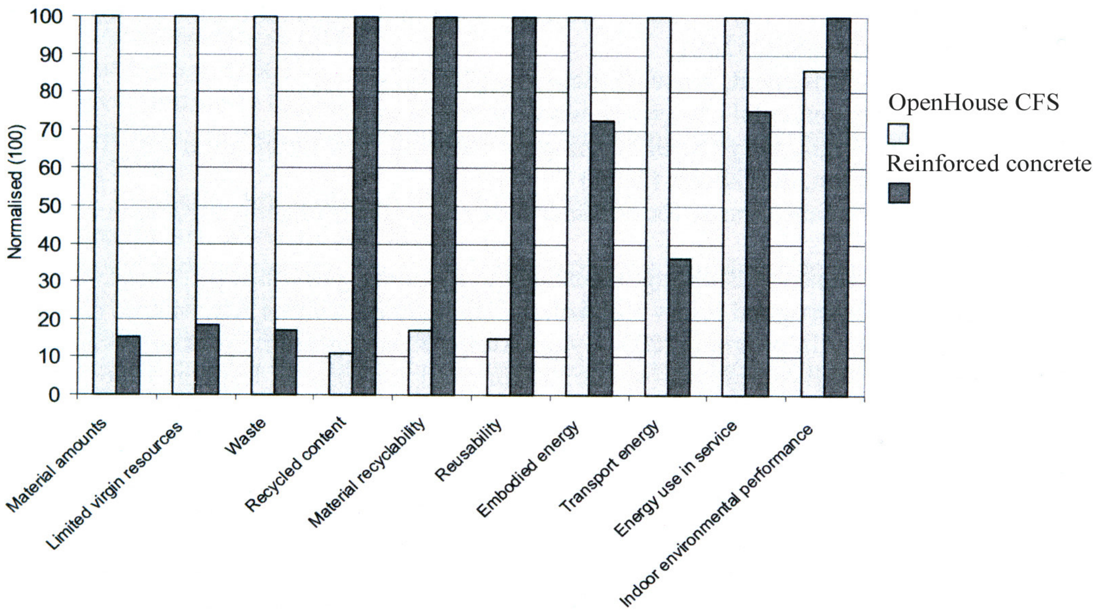

Figure 4. Normalised comparison of sustainability parameters between the Sweden OpenHouse CFS system and the national average reinforced concrete system (Widman 2004).

production, already in action in the building sector and finalized to the continuous improvement of the processes, can cooperate with the issues of the environment safeguard. Its new productive logics constitute a factor of connection with a wider environmental responsibility, converging toward processes of prefabrication finalized to a low impact in the use of resources, in the organization of the productive sequences and in the management of the products cycle.

Moving more of the construction process from the building site into the relative safety of factory conditions, where efficiency and control can be better managed, seems to have the potential to lead to significant sustainability improvements compared to traditional site-based construction, not only with technical benefits – that include increased speed of production, reduced levels of defects and waste, greater efficiency in the production process, and reduced impact on the environment – but also social benefits, like improvements in health and safety, more stable employment, investment in machinery and development of skills.

REFERENCES

Arieff, A. & Burkhart, B. 2002. *Prefab.* Salt Lake City: Gibbs Smith.

Bottom, D. Gann, D. Groàk, S. & Meikle, J. 1996. *Innovation in Japanese prefabricated house-building industries*. London: CIRIA.

Birkbeck, D. & Scoones, A. 2005. *Prefabulous homes. The new housebuilding agenda*. London: Constructing Excellence.

Craig, A. Laing, R. & Edge, M. 2000. *The social acceptably of prefabrication and standardisation in relation to new housing*, 16th IAPS Conference 21st Century: Cities, social life and sustainable development, Paris 4/7 July.

Gorgolewski, M.T. Grubb, P.J. Lawson, R.M. 2001. *Modular construction using light steel framing. Design of residential buildings*. Ascot: The Steel Construction Institute.

Kieran, S. & Kimberlake, J. 2003. *Refabricating architecture. How manufacturing methodologies are poised to transform building construction.* McGraw-Hill.

Long, K. 1999. EU funds EuroHouse research. *Building Design* 1382 12/02: 5.

Trebilcock, Peter J. 1994. *Building design using cold formed steel sections: an architect's guide*. Ascot: The Steel Construction Institute.

Widman, J. 2004. *Sustainability of modulus construction. Environmental study of the OpenHouse steel system*. Stockholm: The Swedish Institute of Steel Contruction.

Widman, J. 2005. *Sustainability of steel-framed multi-storey buildings for commercial and residential use*. Stockholm: The Swedish Institute of Steel Contruction.

Jee - Janela Eco-Eficiente (Eco Efficient Window); Development of a high performance standard window.

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ABSTRACT:
Eco Efficient Window (JEE) it's a design and R&D project, consisting in the production of a high performance window to be applied, both in refurbishing and new construction. JEE aims to reduce the energy demands and the CO2 emissions, during the Life Cycle, tacking advantage of sun radiation and recyclable materials on its construction.
Patented as a standard indivisible object, the Eco-Efficient Window functions 24h a day, in buildings south facing and good envelope conditions. JEE is composed by two systems that respond to different phenomena:
1) Span (glazed window or door) - daylight, ventilation and acoustics;
2) Thermodynamic (vertical part of the span): sunspace ventilated Trombe Wall, facultative electrical heating backup system to increase autonomy to the object, and reactivity to the natural processes, avoiding the use of another acclimatization system, saving money and resources.
To respond to the conceptual and technological objectives, the methodologies had to be solid and clear, finding in the final drawing, the correct compromise between: visual aspects, technological performance, eco-efficiency, and cost/benefit values in a large scale production.

1 INTRODUCTION

The building industry, being one of the most important economic sectors, resists to innovation, and still relies on traditional technologies, methodologies, legislation and production lines, that are somewhat "old fashioned". However, new products and innovative technical solutions are gradually coming out, pushing positively the construction sector productivity indexes, leading to a better quality of the building systems and increasing the global living standards (doing "more, with less", reducing the construction environmental impacts). Several studies have shown that energy consumptions in buildings can be reduced more than 30%, if energy-efficient solutions are adopted. But, even with a growing sensitiveness, persists a lack; of energy efficient products or eco-efficient standard technologies on the market.

"SOLAR TRAP-architecture", found in this void, the motivation to develop an idea, and to create "synergies" with the Civil Engineering Department of Minho University, to join their experience working on the field of bioclimatic architecture and in physical performance of building materials and technologies. This experience gave us the ability to clearly identify some common problems, to create methodologies and the correct tools to solve such a complex problem. So, the Eco Efficient Window (JEE) was the right opportunity to develop a design and R&D multidisciplinary project, consisting in the industrial production of a window, which integrates high standard technological solutions, for thermal, acoustic, ventilation and visual performances. As an innovative project, JEE aimed in the first place, to put questions and to give creative answers to the citizens, projectors, entrepreneurs and constructors, following recent political strategies to rationalize the use of energy and minimise the dramatic environmental impact of the buildings. In that sense, eco-design is not only a tool, but also a mean to change, from a linear destructive paradigm, to a new ecological and circular civilization. Another objective of JEE project, was to go beyond the established "common-sense" of projecting the exterior spans of buildings, only as aesthetic architectural symbols, forgetting that, they are a fundamental element of the façades, acting as important filters of physical phenomena linked to heat, light and sound, that occur between the interior and exterior of dwelling spaces. JEE also wanted, since the very first moment, to be a large spectrum conceptual object, to be applied both, in new and in refurbished buildings, trying to refresh, with a new window system, the exterior image of an immense amount of unqualified buildings – constructed since de 60´s, were JEE can be easily applied, in good performance conditions, contributing to give them a second life, without them being demolished. Finally, JEE, wanted to, give a low-tech response to complex issues, without compromising their simplicity, versatility, ergonomics and operational aspects.

To achieve such an ambitious objective, the project methodologies had to be solid and clear, finding in the final drawing the right compromise between: design concepts and aesthetic aspects, technological performance, eco-efficiency, and cost/benefit values on a large scale production. The A.Solar and U.Minho teams, followed latter by the SAPA-building systems team, never had hermetic postures. The ideas flowed between teams, in brain storming encounters. But finally, although the strict directions of the Visual DOE 3.1 and Ecotect software simulations models were respected, intuition played very important role, in what concerns the energy issues, and architectural or design thinking. That's why, it is so important to architects, to have a comprehensive knowledge of basic physics. Architects and designers have a trained capacity to visualize and resolve abstract 3d problems, and understand that energy flows in 3dimentional complex space geometries. So, with proper training, they can integrate those issues, from the very beginning of the project. But the scale of the phenomena is both interactive and infinite in space time and scale; from the atom to the universe, passing by the materials, the biosphere and human behavior. The task is immense. As creators, we know, that every drawing action, plays a role, under our great energy source, the Sun.

First Steps:

1) Form / Function (methodology)

a) Design Team – The tasks started before the software validation models, trying to find as much as possible combinations and drawing possibilities, to shape the very first idea (to attach to a window, two basic passive solutions, a sun-space, and a ventilated Trombe wall), and to find the right combination between: winter, mid season, and summer solar heat gains, energy dynamic flows, daylight and visual aspects. Our intuitions were later confirmed by software outputs. It was a very creative stage, and a lot of interesting ideas were explored. The "Eureka moment" came. The option: "sun space and Trombe wall vertically disposed to the side of the span", was chosen. An "insulation door and sun radiance concentrator" was added, to improve the heating power of the sun, into the Trombe wall accumulator (different stages Fig.1).

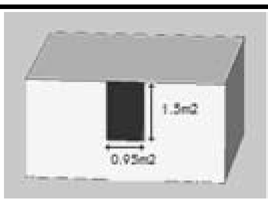
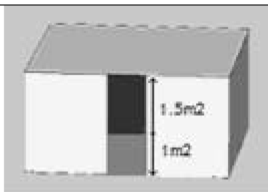
Fig 1 design research stages

b) Dimension / Standard measures – We started to take notes, of the measures of different windows. 300 files were opened with the following inputs: photos; address; dimensions; and building system. Soon, that task showed results, but it was too difficult to conclude. So, we started inquiring directly, windows building system industries and appliers, by mail or phone. The results offered more possibilities, as how to define the correct dimension of a standard window. The most common Height (related to the concrete portico system) was under or 2,4m; Width = 1,5m; Depth = 0,31m.

Fig 2 Typical refurbishing “JEE buildings”

c) Case Study characterization: - Building site – Guimarães; Meteorological data - monitorized on site; recent construction; south facing orientation; domestic occupation; LCA 20years, error margin 5%.

Envelope conditions:
- Ext. wall/40 cm - U = 0.48 W/m2K
- Int. wall/15 cm - U = 2.11 W/m2K
- Pav - U = 2.11 W/m2K
- Roof – U = 2.84 W/m2K Last line of first page

	Model	Descr.	Option	Necessities	
Case 1		A_p=25m^2 A_{env}=1.425m2 A_t= 0 m2 V_c=62.5m^3	Lateral shaded. Trombe wall - No.	HNec.t=	913 KWh
				HNec.n=	681 KWh
Case 3		A_p=25m^2 A_{env}=1.425m2 A_t= 0 m2 V_c=62.5m^3	Lateral shaded Ventilated Trombe wall	HNec.t=	898 KWh
				HNec.n=	630 KWh

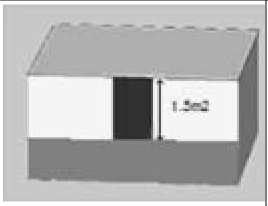
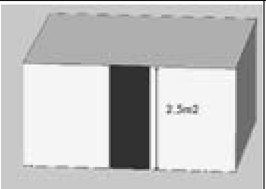
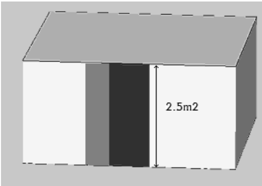
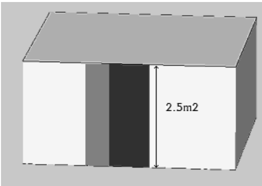
Case 4		A_p=25m^2 A_{env}=1.425m2 A_t= 5 m2 V_c=62.5m^3	Lateral shaded Ventilated Trombe wall	HNec.t=	841 KWh
				HNec.n=	456 KWh
Case 7		A_p=25m^2 A_{env}=2.375m2 A_t= 0 m2 V_c=62.5m^3	Lateral shaded - No Trombe wall - No	HNec.t=	743 KWh
				HNec.n=	560 KWh
Case 8		A_p=25m^2 A_{env}=2.375 m^2 A_t= 1.25 m2 V_c=62.5m^3	**Lateral shaded - No** **Ventilated Trombe wall**	**HNec.t=**	**726 KWh**
				HNec.n=	**499 KWh**
Case 9		A_p=25m^2 A_{env}=2.375 m^2 A_t= 1.25 m^2 V_c=62.5m^3	Lateral shaded - No Trombe wall	HNec.t=	719 KWh
				HNec.n=	539 KWh

Table 1 - Confronting solutions with heat necessities

2) Materials - Thermal properties:

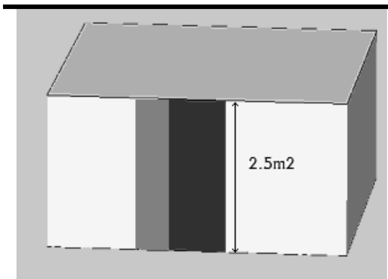
CASE STUDY	MATERIAL TROMBE WALL	Thickness (cm)
	1. Granite	15
	2. Earth - Adobe	15
	3. Ceramic - Red clay	15
	4. Stone - Schist	15
	5. Concrete	20
	6. Stone – Granite	20
	7. Earth - Adobe	20
	8. Ceramic - Red clay	20
	9. Stone - Schist	20

Table 2 – Case Study representation, material thermal performance

CASE STUDY	GLASED				Trombe Wall				Heat Nec (kWh)	Night (kWh)
	Lat. Shaded	High (m)	Large (m)	Area (m^2)	Ventilated	High (m)	Large (m)	Area (m^2)		
CB	No	2.5	0.95	2.375	Yes	2.5	0.5	1.25	726	499
1	No	2.5	0.95	2.375	Yes	2.5	0.5	1.25	725	496
2	No	2.5	0.95	2.375	Yes	2.5	0.5	1.25	729	516

3	No	2.5	0.95	2.375	Yes	2.5	0.5	1.25	727	503
4	No	2.5	0.95	2.375	Yes	2.5	0.5	1.25	726	498
5	No	2.5	0.95	2.375	Yes	2.5	0.5	1.25	727	500
6	No	2.5	0.95	2.375	Yes	2.5	0.5	1.25	726	496
7	No	2.5	0.95	2.375	Yes	2.5	0.5	1.25	730	518
8	No	2.5	0.95	2.375	Yes	2.5	0.5	1.25	727	504
9	No	2.5	0.95	2.375	Yes	2.5	0.5	1.25	726	498

Table 3 – materials and heat necessities

Analysing (1) (2) steps:

The vertical arrangement increases on all respects the energy performance of a window with an associated thermal system as we want to create.

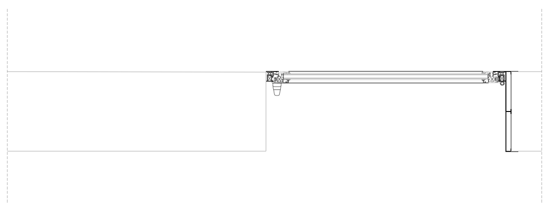
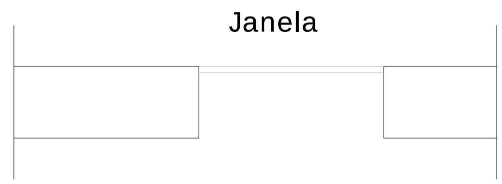
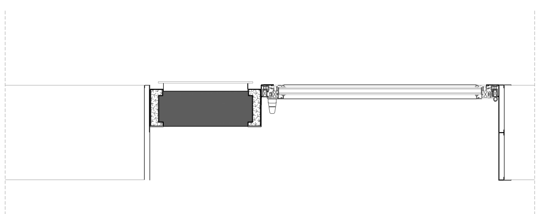
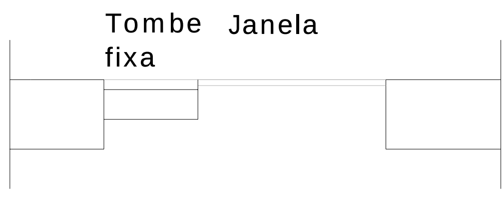
Allowing sun radiation to penetrate more profoundly into the interior space, by the glazed span, the direct sun gains and natural daylight reflection possibilities are increased. The thermal performance of the attached ventilated Trombe wall system, being vertically disposed, will work better than others - horizontally disposed (see. Table1). This can be justified because, if the energy flows vertically, there is an increment of heat exchange properties - by contact, radiation or convection. Natural thermal circulation will be also be increased. (case 4) (case 8).

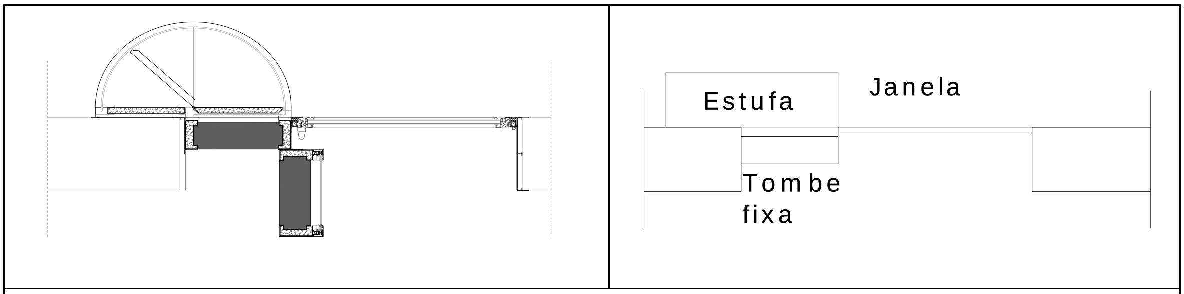
Analysing the thermal properties of the materials, we can conclude that granite, followed by concrete; achieve better results in thermal accumulation. By increasing the thickness of the Trombe wall, there is an increment of heat necessities to achieve space thermal comfort.

3) Technology / Functioning:

a) Simulating association - Trombe Wall + Sun Space:

Table 4 – Thermal influence of associated systems.

<table>
<tr><th>Schemes</th><th>Visual DOE3.1</th></tr>
<tr><td></td><td>
</td></tr>
<tr><td colspan="2">1- Window</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td colspan="2">2- Trombe Wall</td></tr>
</table>



3- Trombe Wall+ Sun Space

Case Study	Glazed			Trombe				S. Space		Heat needs (kWh)	Night consum (kWh)
	H (m)	W (m)	area (m^2)	Vent	H (m)	W (m)	area (m^2)	Ventil.	area (m^2)		
1	2.35	0.95	1.43	-	-	-	-	-	-	686	357
2	2.35	0.95	1.43	Yes	2.35	0.45	1.06	-	-	635	310
3	2.35	0.95	1.43	Yes	2.35	0.45	1.06	Yes	0.8	615	289

Analysing 3a) Step: Associate a Sun Space to a Ventilated Trombe Wall increase, 18% to 19% the energy efficiency of the single glazed system. The study showed that the need to include an electrical backup system.

b) Fixing the Technology:

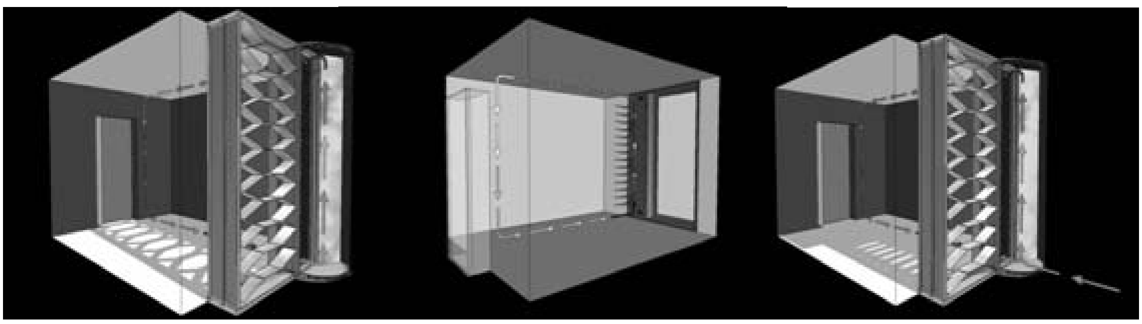
Patented as a standard indivisible object, the Eco-Efficient Window is composed by two systems that respond to different phenomena:
1) Span system (Glazed window or door) - daylight, ventilation and acoustic control;
2) Thermodynamic system (attached to the side part of the span) including: a sunspace, a sun heat accumulator following the technological principles of a "Ventilated Trombe Wall". An electrical heating backup system can also be added to the thermo-accumulator, to increase reactivity to the natural processes, and also, autonomy and flexibility to the object, avoiding the use of another acclimatization system, saving money and resources. The JEE functions 24h a day in optimal conditions, in buildings south facing, and good envelope system:

Fig.2 "Eureka moment"

Winter and mid season, sunny and light cloudy day:

Insulation door opens, facing a mirror to sunlight. That helps to concentrate the sun radiation into the thermal accumulator. This system keeps the energy to be released at dawn to interior spaces. Meanwhile the direct sun radiation heats the sunspace. This green house effect increases a thermo circulation (by natural convection), passing thru ventilation grids, heating the interior rooms.

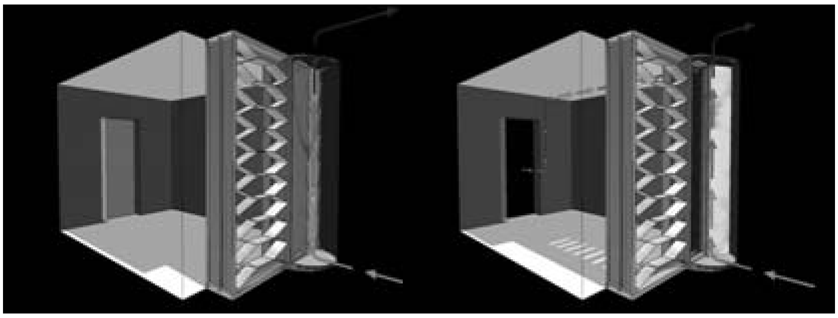
Fig.3 – winter / mid station – sun space during the day, heat radiation and convection at night



Summer and mid season sunny day:

Insulation door is closed, but an upper ventilation canal is open, functioning as a “thermo siphon”, “sucking” to the exterior all the heat gains concentrated in the ceiling. That occurs, because the sunspace ventilation system is open, allowing the air flow to go up, causing a depression and suction phenomenon.

Fig.4 – Summer / mid station – thermo siphon, night cross ventilation mode.



A blind system, made in polished aluminum, disposed in the glazed part of the span, improves daylight reflection into the interior white ceiling, diffusing the sunlight, avoiding electrical lighting, to be used to achieve visual comfort in dark cloudy days. The glazed, also allows important direct sun heat gains in winter and mid season. In summer and in some mid station sunny days, the direct gains have to be retained outside, by shadowing the glaze.

Building the Prototype:

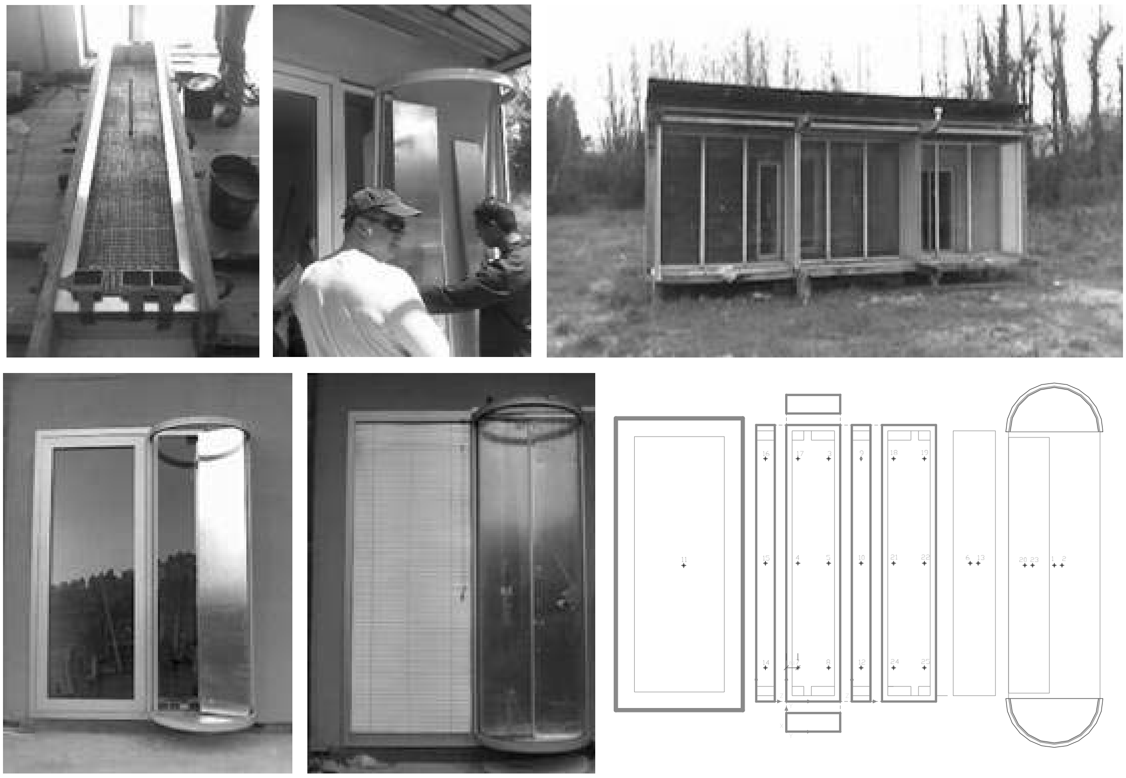


Fig.5 Instrumentation

Final Conclusions at this point (Jun 2007):
The Eco-Efficient Window is yet, a "work-in-progress".
Already patented, we want to conclude the prototype instrumentation and after, to proceed with some improvements, and start to build the pre-industrial prototype.
Until now, we faced problems that can be solvable. The first prototype had problems with the night insulation door, and the test cell, was made with feeble envelope insulation. So, there are losses in the system efficiency.

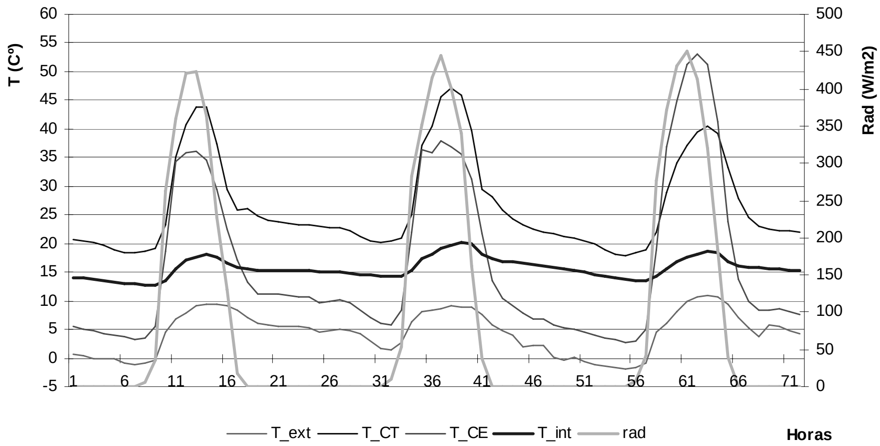


Table 5 – 3 Winter sunny days 06, before improvements, we see that the sun space (CE), and the Trombe accumulator (CT), functions. But the comfort level, due to the test cell insulation, is not at comfort levels.

Only recently we could do the necessary improvements. But until now, we can already achieve 20% of efficiency, comparing JEE tech, with a normal double glass and thermal cut window; Our aim is to pass over 30%, to push payback time, to less than 9 years (thermal system+window).

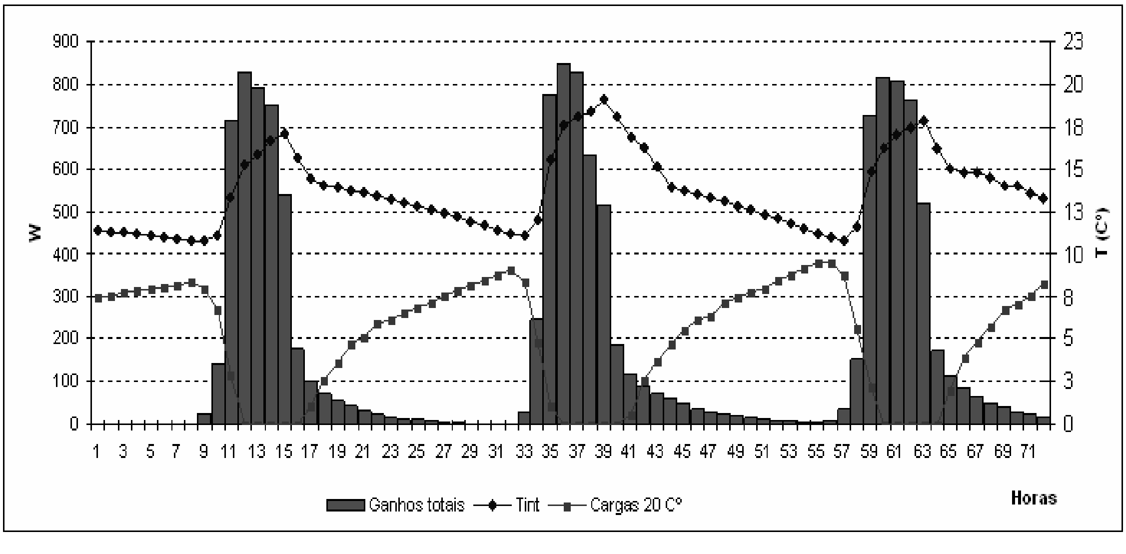


Table 6 – Dec. sunny days; energy balance. Improving insulation, JEE, as to provide above 300wh (night)

This graphic was made after tuning the test cells environment in VisualDOE improving the insulation. As we can see, JEE can provide the necessary heat charges to maintain the comfort levels during the day. As previewed, we can achieve 400Wh gains in a December sunny day between Trombe and Sun Space. At night, the backup system must provide 300Wh to maintain the room comfort levels. Numbers that can be easily achieved, making few adjustments.

A research on the integrated system for efficient management of construction Site

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ABSTRACT: In order to efficiently manage the construction industry, informatization process involving integration of construction data is required. In this integrated environment, the whole process of construction can be organically connected and when this is applied into practice, production control, cost control and other various tasks could efficiently be carried out. This will lead to a significant increase in productivity of construction industry. Data at each stage of construction should easily be able to be utilized in practice and should also be able to be used in management of other similar construction process. This research puts highest emphasis on EBS (Element Breakdown Structure), which is a classification method centering on elements of the construction outcome. On this, WBS (Work Breakdown Structure) – focusing on the process of construction – and CBS (Cost Breakdown System) – focusing on the cost – are connected together to collect data on each process of construction. Through this, CIBS (Construction Information Break-down Structure) model will be proposed which will efficiently present the flow of data through each stages of construction.

1 INTRODUCTION

In construction projects, the number of apartment-store complexes has increased recently and the constructions are showing a trend of becoming ultra-high and extra-large. However, for an efficient construction planning, data on past similar projects is needed to be collected but the technique of collecting such data is lacking. Also the site managers and the managerial staff, rather than implementing new information technology for construction site management, tend to rely more on construction experiences and knowledge. Due to these reasons, sharing of information between participants in a construction project is made difficult and hence browsing real-time information and tracking the progress of the project is also made difficult. Therefore, there is the urgent need to consider introducing tools for data sharing and there needs to be a system established to connect various construction data for integrated management. This will help to shorten construction period, reduce cost and increase the quality of product.

The existing domestic researches on construction information have focused on how to collect together the data used in construction management or on mere visualization of data. Therefore these researches could not solve the problems raised by the inappropriate information system and also, rather than focusing on the data flow in each stage of construction; they focused on individual functional units such as cost management, accounting, material management and labor management. In other words, application systems for a specific stage or an individual function has been developed a lot but development of a system for holistic management of all the construction stages and processes is still not enough.

In this research, centering on EBS (Element Breakdown Structure) – system of classification centering on elements of the construction outcome – and by combining it with WBS (Work Breakdown Structure) – focusing on progress of construction – and CBS (Cost Breakdown Structure) – focusing on the cost – data on each stage will be collected. Through this, CIBS

(Construction Information Break-down Structure) model will be proposed which will efficiently present the flow of data through each stages of construction.

2 CIBS Model

2.1 *The general idea of CIBS*

The previously researched WBS and CBS integration models, by themselves, possess the problem of making acquisition of the needed data and identification of troubles in each stage difficult. That is to say, these models fail to achieve effective management of blueprint data which, among various construction data, plays the pivotal role. The demand for implementation of data produced at the designing stage onto the actual construction and also demand for systematizing vast and dispersed data for maintenance management cannot be well met with the existing models. To create a construction management to meet these demands and for effective data management in construction stages, data management of elements that is linked with location information of the blueprint is needed. This is because in stages of construction, data often needs to be referenced on specific regions. Constructing element-based data system will help to effectively present data flow in various stages such as designing, construction and maintenance. Therefore this research, differing from decentralized and fragmented manner of past data management, systematizes data focusing on EBS and the corresponding data on blueprint. Such element-based data management enables easy browsing, inputting and altering of information by the user. Consequently it enables smooth data transfer of construction experience and design data, maximizing utilization of construction information.

By focusing on EBS and linking it with existing WBS and CBS, the means to effectively process data from various construction stages such as design, construction and maintenance are provided. Especially, by enabling efficient management of various construction data linked with the blueprint, the prospect of implementing data flow in design and maintenance stages, which as been previously overlooked, into the construction management system is presented by this research. On this classifying system integrating EBS, WBS and CBS, construction data-flow system, with each stage concretized, is combined. This is the model, CIBS (Construction Information Breakdown Structure), this research proposes. CIBS model, as can be seen in [Fig. 1], is not only a classification of data but is a dynamic model that, within the system, contains data flow in construction process. Hence it can be said that this model is practical in that it flexibly meets the continuing changes in construction flow.

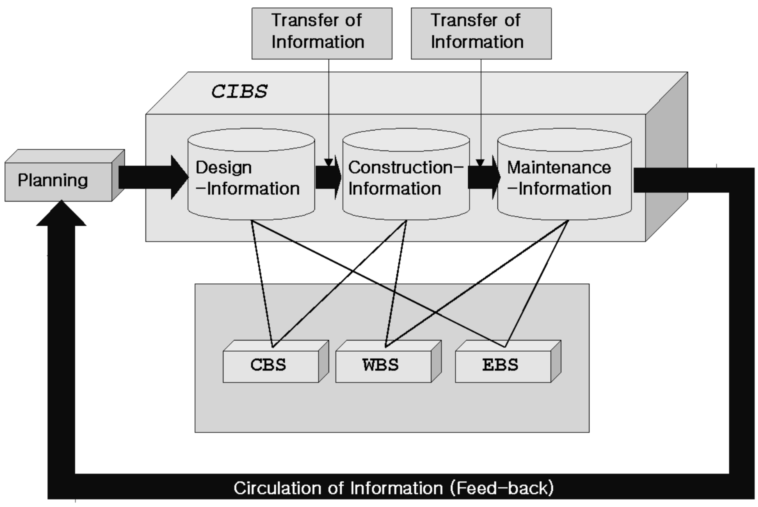


Fig. 1 Division system and information flow of CIBS model

2.2 *Content of CIBS model*

CIBS model, as can be seen in [Fig. 2], covers the designing, construction and maintenance stages of projects and is based on integrated system of EBS, WBS and CBS. Based on this integrated structure, element breakdown is used in CIBS model. These elements are the unit of elements in EBS, the object of construction in WBS and value estimation units in CBS. This makes the representation of data flow in construction more detailed and specific which eases extraction of data. Such qualities of element breakdown in CIBS enable different data systems to be applied for different stages of construction, forming a more incorporated sorting system.

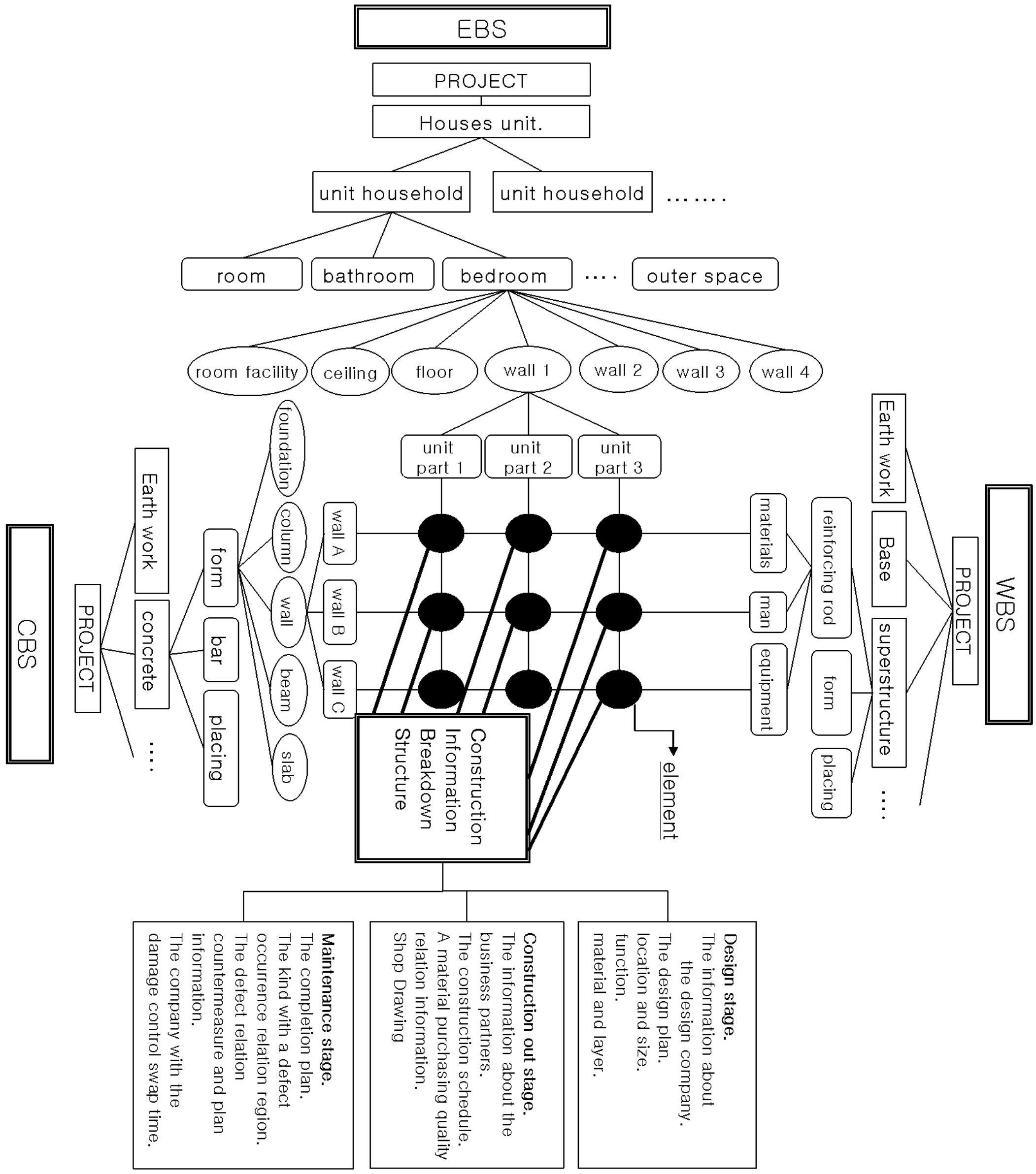
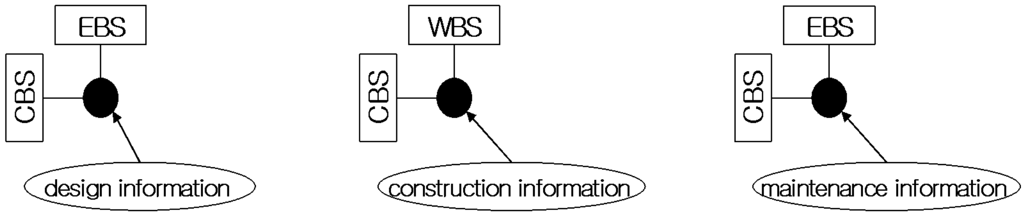


Fig. 2 The structure of CIBS model

In the designing stage, value estimation on each part is important data. Therefore, as can be seen in (a) of [Fig. 3], using mainly EBS and CBS, data system is combined. Then on this, data on designing company, blueprints, size and location of elements, functions of elements, material composition of elements, nature of layers and other data is added to form CIBS model which contains data needed for executive budget planning and estimation of cost.

Since in the actual construction stage cost management on different processes of the project is important, data sorting should focuses on each and different construction processes and on each items. Therefore, as can be seen in (b) of [Fig. 3], CIBS model for construction stage mainly uses WBS and CBS and on this integrated system, data on suppliers, construction schedule, data on material purchase, stock data, shop drawing and other data is added, presenting data flow concerning construction progress and construction quality control.



(a) CIBS of the design stage model (b) CIBS of the carrying out stage model (c) CIBS of the carrying out stage model

Fig. 3 A structure of CIBS model according to construction stage

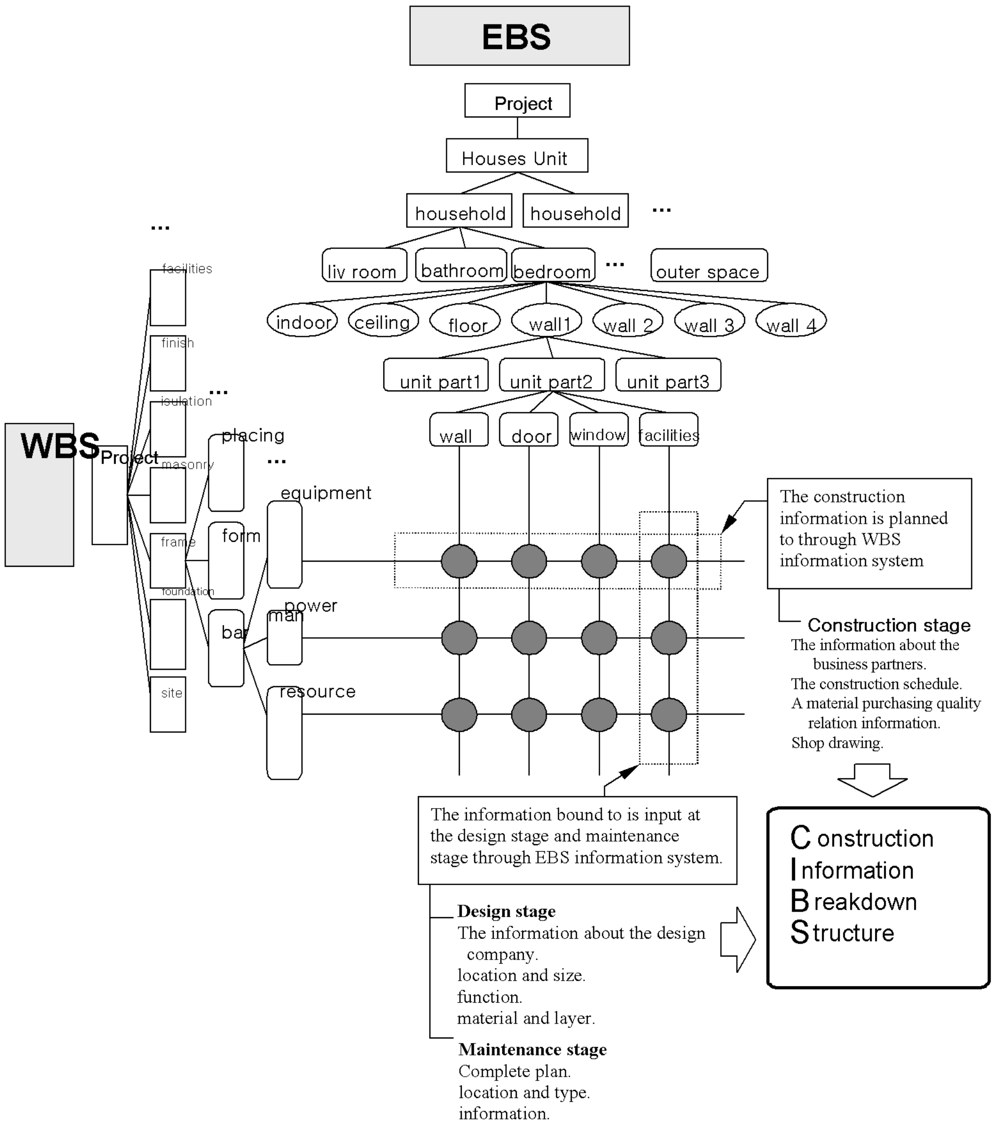


Fig. 4 The structure of CIBS model (Maintenance)

In the maintenance stage, defects occur in various elements but the actual maintenance is performed according to different construction processes. As can be seen in (c) of [Fig. 3], in maintenance stage, EBS and WBS are mainly employed to form CIBS model, including data such as: defect areas and types, programs or solution for defect control, outcome of fixed defects and schedule and contracted companies for maintenance and replacements. This will present data flow to aid maintenance-related operations and the general running and administration of the constructed project.

Among different stages of construction, maintenance data arises in all the stages of construction and such data has the potential of being used in new projects when it is accumulated. [Fig. 4] reconstructs the CIBS model for maintenance centering on data integration.

More detailed depiction of WBS in CIBS shown in [Fig. 4] is shown in the structural diagram of [Fig. 5]. In each major process, there are minor processes and it consists of various data concerning these minor processes – construction data, material data, manpower data and tool data.

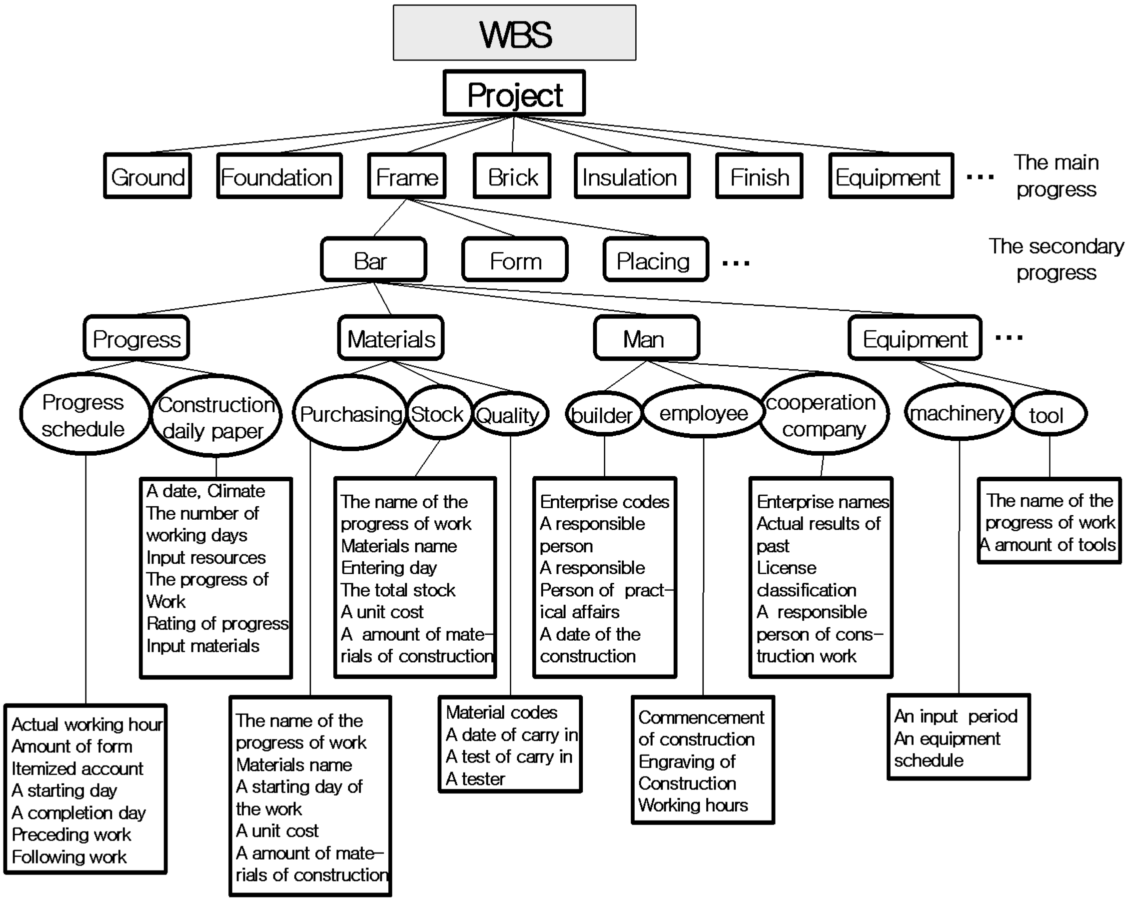


Fig. 5 The structure of a construction kind grouping system (WBS)

3 Element Breakdown Structure (EBS)

CIBS model in this research has been formed focusing on location data of blueprints and related element breakdown structure. EBS, as well as being integrated with CBS and WBS, is formed to ideally present data in each construction stage. Element-based data system has been focused so that it will be a practical construction management system able to be applied to the maintenance stage in areas like defect control and running and administration of buildings.

In EBS, classification of elements can be defined as identifying the properties of walls, slabs, roofs and other elements which are either spaces or boundaries of spaces in buildings and going on to systematically sorting elements according to its properties. Also, together with element breakdowns such as walls, slabs and roofs, data concerning the interior of a spatial area should also be considered. In other words, data concerning the furniture, electronic and mechanical installations (heating and sanitary equipments), various utensils in the bathroom and the elevator should be considered.

EBS does not merely disassemble construction elements but it interconnects with other data concerning the composition of elements (e.g. materials for elements and layer structure) and also with data such as dimensions of elements or unit cost of materials. With this more integrated approach, the flexibility to integrate with WBS or CBS is provided.

As can be seen in [Fig. 6], EBS in CIBS model has a descending hierarchy of: from project to space, from space to components of space and from components to units or components. Data in construction possesses various different properties and meanings. Because of this, we should not only focus on the sub-category the data falls into but also should consider the properties of categories that are higher up in the hierarchy.

For example, in a bedroom space, data can be sub-categorized into components such as walls, slabs and roofs but separate consideration is required on the holistic property that a spatial area of bedroom itself possesses. In this case, separate consideration would also be required to address the property of a spatial area.

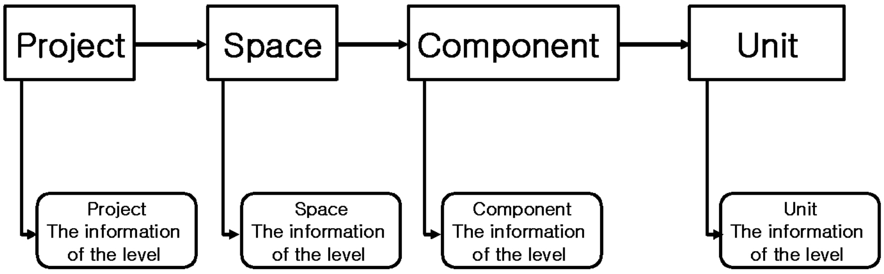


Fig. 6 The grade of rank of EBS

In EBS, spatial elements are the most important and include components which have units such as doors, windows and equipments. Component data, which consists of the majority construction data, are formed like [Fig. 7] in order to deal with various different data and for smooth integration with WBS or CBS.

Table 1. Information examples of each level

The level of a grouping system	Correspond information of an each level
Project	Site location, The number of household, Unit dimension, Owner, Application information, etc.
Space	The formation of the space, Use and function, etc.
Component	Location information, Topology information, Size, Quality of material, etc.
Unit	Information of measurement, property and location.

Data systems of components consist of location, composition and dimensions of components. For component's location data, there are: function the spaces at the two sides of the component, function of the space and function of the component. For component's compositional data, there are layer structure of component and materials of the component. For component's dimensional data, there are measurements of the component such as the length, height and width and also are location marking of components. [Fig. 8] shows the general flow of this EBS.

Location	Function of both space at interface. (ex: bedroom, living room, kitchen...) Function of interface. (ex: wall, floor, roof)
	+
Composition	A layer formation of a interface. A material condition of interface.
	+
Dimension	Indication of interface location.

Fig. 7 Information system of unit part

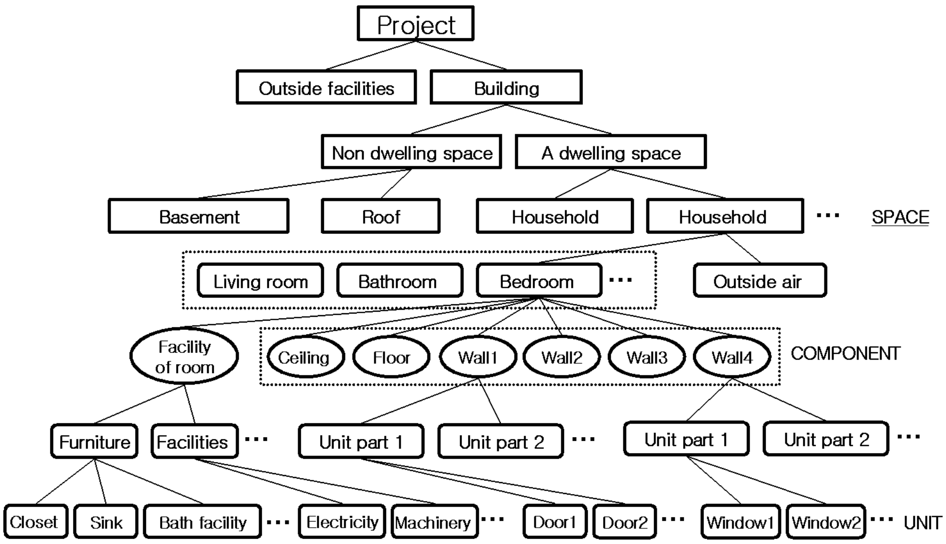


Fig. 8 The structure of division system (EBS) according to location

4 Integration of data on construction process and elements

The integration of data on construction process and elements that this research proposes is a basic means of accommodating the existing site operations as much as possible and at the same time integrating construction data to bring an improvement. Therefore, operations that use WBS and CBS must first be analyzed to identify the data flow in each operation. Generally in a construction project, there are three parties involved: a party that orders the construction, party to design and supervise and party to undertake the construction. These three parties under to the process of: planning – designing – construction – maintenance - dismantling.

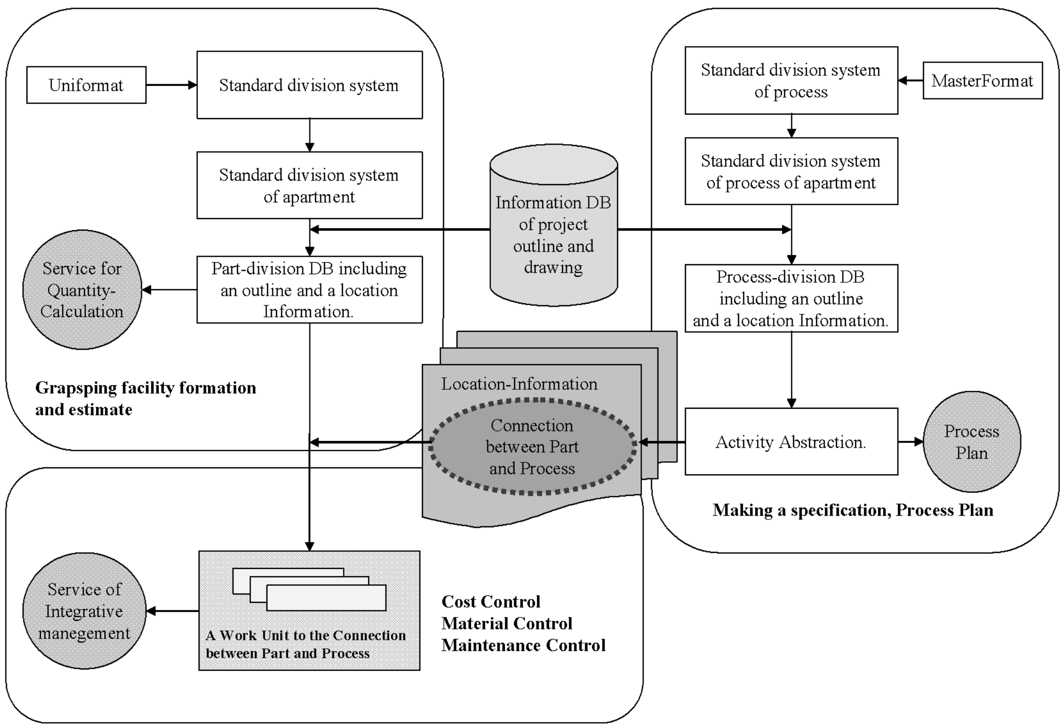


Fig. 9 A concept of connection between part and process

Because construction process is planned based on the blueprints and specifications, it can be said that the location is decided at the stage of planning. Since the expenditure breakdown is based on the quantity calculation of elements, the concept of element enters the expenditure breakdown at an early stage. Therefore, by extracting common location code based on the blueprint, elements and construction process can be integrated. As a result, when the integration element system and construction process occurs, both will be possessing location data. Such data is built in within the project database.

Integration of element data and construction process data that this research proposes is based on location data. For example, element and construction process data with same location data can be extracted to form basic integration table. Based on this table, integrated operation is possible. Especially processes like water supply and sewage installations that have the areas to be worked on are pre-considered, can be integrated directly with elements with same location. However, when elements with the same location data require a number of operations, locations of elements and operations can be connected to form integrated operation at minor level.

5 CONCLUSION

In order for researches in integration of construction data to be applied in practice, utilization of data must be increased and usage in management of other similar projects should be enabled. Also a method of managing site data based on the actual elements of construction needs to be looked into. Hence this research has sought to improve the method to enable collection and application of data on each elements of construction outcome and sought to prevent wasteful overlap of investment in data management. Also, responsibility on the part of construction parities was increased by clarifying the responsibility on each element. By enabling construction process to be presented multi-dimensionally, visual information was offered.

The research can be summarized as follows:

1) CIBS model was proposed which integrates various stages of construction. This is achieved by integrating 'process-centered' data and 'cost-centered' data in an 'element-centered' manner. The result of CIBS is that it is possible to effectively manage data in construction process.

2) By developing CIBS model which integrates existing WBS and CBS with EBS at the core, data in stages of construction – design, construction and maintenance – was able to be processed effectively.

3) CIBS model is a dynamic model which contains data flow of construction process within the system and is a practical construction management system which flexibly adapts with continually changing construction data flow.

ACKNOWLEDGEMENT

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REFERENCES

[1] Lee Kyo Sun, Park Hwan Pyo, Oh Uno, Park Sang hun. A study on the establishment plan of integrated construction information classification, Korean Journal of Construction Engineering and Management, 2002.6.

[2] Song Hyuk, Lee Han Min, Ryu Seong Ryong, Han Choong Hee. A fundamental study on the CIBS model for the integration of the construction information, Journal of the Architectural Institute of Korea, 1998. 11.

[3] Kim Sun Kuk, Kim Tae Hui, Joo Jin Kyu. Design of a Maintenance Management System for Apartment Building, Journal of the Architectural Institute of Korea, 2004.3.

[4] Yun, Seok Heon, Kim Seong Sig. Using the common-WBS based on the Construction Classfication System for the integration of Schedule and Cost information. Korean Journal of Construction Engineering and Management, 2005.12.

[5] Lee Sang Hun, Han Choong Hee, Song Hyuk, Lee Han Min, Lim Jong Sung. Object definition and shared information model on design/construction phases for building integrated database, Proceeding of Conference in Architecture of Korea. 1997. 10.

Recycling prefabricated concrete components – a contribution to sustainable construction

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ABSTRACT: This contribution describes the latest development in the area of recycling of building parts from disassembled concrete prefabricated parts from GDR housing construction. The use of this method of recycling in construction is limited to structural engineering. According to knowledge gained during recent years, current activities including advantages and disadvantages of this construction method are shown. Moreover, the economical and ecological aspects are discussed and the future developmental potential of construction with recycled building parts is introduced.

1 INTRODUCTION

Already since 1998 there have been activities at the Institute involved in reusing demolished prefabricated components from buildings of large apartment settlements. In those days, still rather surreptitiously, one could already see that a not inconsiderable excess of residential buildings would have to be "taken from the market" in the new German provinces during the coming years in order to support the value of real estate and to work against the neglect of large areas of eastern Germany.

Since the focus of the problem of vacant buildings was often to be found in the newly built large apartment complexes during the GDR period, one was usually confronted with industrial prefabricated construction.

The building quality of this construction method was already known in 1998. After the change of political system, extensive reports on the building condition analysis and on renovation and modernisation costs from various sides were ordered. The IEMB occupied itself for the first time in 1993 with a 10-storey panelised structure intended for demolition and investigated the building-part quality there before the demolition [Hillemeier et al. 1994]. A reuse was not planned, despite the generally good building substance. The simultaneous investigations carried out concerning roof construction and renovation in concrete prefabricated buildings of the GDR apartment construction series resulted in the recognition that the prefabricated roofs could be dismounted without difficulty. The building quality was still so high after the dismounting that a reuse was possible [Spaethe et al. 1993].

Starting in 1994, the reuse of building parts from GDR demolished buildings was scientifically investigated for the first time [Mettke 1995]. Rubbish avoidance and protection of resources were in the foreground. The positive environmental aspect of reuse of building parts was clearly emphasised as the result of the studies.

Only starting in 1998 did the recycling investigations lead to first pilot studies on practical projects [Vogdt et al. 1998]. All the pilot studies attempted to accept the original building part geometry and to complete it with new materials in case of discrepancies.

The state support beginning in 2000 for the removal of derelict living spaces gave the recycling projects a large number of usable concrete prefabricated parts. The first pilot houses could be realised in 2001 with these. In the projects, alongside the positive characteristics (in those days, the actual realisation of a building from recycled materials of approximately the same new building quality was a success even amongst professionals), negative aspects were also shown, however. For example, the insistence upon the original building-part pattern led to limitations in the foundation design. Retaining the original stairwells from multi-storey buildings led to a disproportion of connecting surfaces to usable surfaces in the case of small buildings [Asam et al. 2005a]. Recycled walls were at times completed by new building materials in order to attain a variety of facades. These were usually completed in masonry construction. The combination of prefabricated parts and traditional building methods generally led to delays in the construction operation, then leading in turn to increased expenditures. The insight gained from these practical projects – all of them, including smaller apartment buildings – was clear. Although hardly a project could boast great economical successes, the persons involved were of one mind – that it is technically feasible. The efficiency depends to a great extent upon the surrounding circumstances.

2 INSIGHTS GAINED FROM CURRENT WORKS

Starting in 2003, another attempt was made to optimise the recycling building method with concrete prefabricated components. The works were concentrated on the area of recycling in housing construction and in structural engineering in a broader sense as well [Asam et al. 2005b]. The following decisive investigation points of emphasis were recognised:

1. The number of suitable donor buildings.
2. The quality of the recycled components.
3. The scope for architectonic design when building with recycled components.
4. The construction and developmental possibilities when building with recycled components.
5. The logistical optimisation when building with recycled components.
6. The economical significance of the method of building with recycled components for the building trade.
7. The ecological advantages of recycling compared to new construction.

The results of the research projects can be summarised as follows:

2.1 *The number of suitable donor buildings*

The number of suitable donor buildings is sufficient during the period 2000 to 2010 through the reconstruction measures in eastern Germany. Approx. 310.000 apartments built with prefabricated parts are to be demolished. Those Demolitions are still taking place, but not nearly so frequently.

2.1.1 *Obstacles*

Only a small number of demolitions are carried out in which the building substance is protected. Usually, only workers' protection and environmental protection are taken into consideration. This procedure is above all due to the fact that the marketing of the building is not applied as a source of building parts. The building becomes – legally, as well – rubbish, due to the building owner's desire to remove it. The demolition company must then guarantee a correct, prescribed treatment of rubbish according to German law of life cycle management. In this, the purity of material utilisation and/or deposit is in the foreground. An entire industry has become specialised in this area, which, for example, keeps crusher facilities available for concrete in order to make recycled crushed stone. This is why the potential suppliers of recycled building parts are not motivated to do this. Since the demolition work are for the most part financed with state means – given regardless of recycling technology – the demolition clients are not motivated to do this, either.

2.1.2 *Improvements*

The introduction of a bonus system for state-supported demolition measures which also consider environmentally relevant aspects could provide the necessary motivation. Similar to the way in which influence is taken on the operation phase of buildings, in which energy-efficient measures are especially supported when constructing new buildings and renovating them, building methods which save energy and protect recourses could be especially supported.

Moreover, a legally clearer demarcation between building product and rubbish should be discussed. The first step in this direction could be undertaken by the building owner, in which he understands his building (no longer being rented out) to be of a substantial value, and allows himself to become involved in the marketing of building parts as a "removal concept." Whether the desire can be transformed into marketing depends in general on the economical advantage.

This can most easily be communicated through a separated bidding procedure of the demolition measures according to building material and building-part recycling.

2.2 *The quality of the recycling components*

The quality was communicated in numerous investigations and can be reliably estimated for the constituent buildings [6]. The recycling quality of the building parts only depends on the reinforced concrete substance in exceptional cases, and especially on the demolition quality and usability of the individual building part in the new network.

2.2.1 *Obstacles*

Since the demolition buildings are generally 20 to 30 years old, one must only reckon with serious damage to the preliminary building substance on areas exposed to the weather. The focal points are especially the balconies and the weathered surfaces of the outer walls. Damages to the substance have been repeatedly found here. A problem not yet solved in demolition, nor in reusing, is that of three-layered outer walls with core insulation. In conventional demolition with ensuing building material recycling, the insulation must be removed before the concrete is shredded. This is very costly. Moreover, it cannot be determined which insulating material has been used without a damaging test. If the widely-used mineral wool has been used, protective measures towards workers and environment must be adhered to during the separation, since the wool is classified as being carcinogenic. The mineral wool problem also applies to reuse, so that outer wall components can only be designated as capable of recycling under certain conditions.

Other components are only suitable in individual cases for recycling due to their geometry. Examples of these are stairwells, lift and rubbish shafts, roof components and bath cubicles. Other building parts are difficult to dismount without damage, such as too-thin separating walls only 5 cm thick.

Storey slabs and interior walls have proven highly capable of recycling. These building parts comprise 42% of the building substance. This amount of recycled materials, theoretically available, is further decimated by damages during dismounting, transport, cleaning and off-cuts during processing. In the end, about 38% good, reusable preliminary building substance remains from a GDR-type apartment building.

2.2.2 *Improvements*

The increase in building-part quality after the dismounting therefore has the highest priority. A reliable method of minimising damages during handling of the recycled building parts is the estimation of the parts. As soon as money enters the picture, the quality increases. Moreover, the qualification of the demolition companies is to be planned. The measures must be integrated into a generally acknowledged quality system in which the certification of the components is also contained. Since at present the investigations are carried out at the level of pilot projects, one must reckon with further optimisation potentials in an overall introduction of the recycling building method. Construction capable of dismounting and recycling must be used more in new constructions as well, in order to increase the reuse quota.

2.3 *The architectonic scope for design when building with recycled components*

Since the basic consideration for the reuse of recycled components was the reapplication in resident construction, it had to be tested how the large wall and slab panels could be used in new contemporary architecture. Design seminars were carried out with architecture students and an architecture bureau in which up to three-storey buildings were to be constructed out of a limited number of components. It was striking with all the participants that a great curiosity for combining with the available building blocks was awakened. As with LEGO building blocks, a completely individual architecture resulted in each design despite the limited number of different building parts.

2.3.1 *Obstacles*

Due to the retention of the original structural module, compromises often had to be made in the function of the apartment floor plans.

2.3.2 *Improvements*

A clear improvement in the floor plans was attained through the geometrical adjustment of some components. Especially the processing of the walls made up for the problem of inflexible door and window openings among the recycled components. One strived to keep the working expenditures at a minimum as well. Additionally integrated new building parts such as stairs brought further qualities into the design. The foreign application of components (e.g. a slab as a wall, pertinent due to a higher clearance height or interior components in areas exposed to the weather, property demarcation walls and garages) also provided good solutions. The application was limited, however, by technological limitations and building-part quality.

2.4 *Construction and processing possibilities when building with recycled components*

It was established in the architectonic design scenarios that a change of the original structural module/grid and, with it, the original components, is a prerequisite for good and functional architecture. There were sufficient processing possibilities in the slabs and interior walls. It was advantageous that the slabs were made of prestressed concrete with immediate bond without end-anchored reinforcement. Through this, the slabs could be cut off without any loss of tensioning force. It was similar with the interior walls. These were exclusively provided with transport and ring-anchor reinforcement. When cutting, one had to take care that they could still be transported. The processing (trimming with the help of concrete saws) should be kept to a minimum. The possible processing costs are given by economic factors. The unchanged application of the component is seen as an optimal application.

Since the original welding joints would often fall off during the processing, a new system was consistently used during the connecting technique. The new joints were completely made of a screwable heavy-lift dowel system to ensure better dismounting in the future. This joint technique is comparable to that of a wooden house.

2.4.1 *Obstacles*

Since the available components are not building parts originally intended for dismounting and/or recycling, all the recycling activities (pilot houses) are subject to compromise.

2.4.2 *Improvements*

Recyclable building components should be planned for the future. The followings pointers are helpful for this.

Component documents of the building and the components are to be on hand until the final removal. A demolition free of destruction or with limited destruction must be planned. One should aim towards a homogeneous combination of building parts. Multi-layered building parts which are difficult to separate should be avoided.

Since preliminary material constructions have a utilisation period of several decades, it is not possible to plan a second application during the production period. The possibility of processing (e.g. saws with concrete) should be taken into account. The reinforcement is to be chosen in the building components so that the component can be freely cut for the most part.

2.5 *The logistical optimal solution when building with recycled components*

The basic necessary condition for building with recycled components is the presence of a sufficient number of building parts. Previous experience has clearly shown that, despite surface demolition measures of prefabricated buildings in the eastern German provinces, the building material “panels” was not available in sufficient quantities since the great majority of the buildings were torn down.

2.5.1 *Obstacles*

Only about 4% were demolished in a way that protected the substance. The cheaper demolition was always chosen when no conditions of environment protection or workers’ protection were required in the demolition. The alternative variant of demolition plus marketing of the dismounted building parts is not taken into consideration, although accompanying dismounting projects have shown that some building parts (usually slab components) can always be directly marketed through the demolition company. This is only possible to a limited extent, however, since the running construction operation must not be disturbed. Already in this situation one can run into delivery troubles in the application of our pilot projects, although the ratio of donor building to pilot projects was approx. 200:1 to 300:1.

A further obstacle is the lack of professional processing possibilities of the components. The "just-in-time" production of the recycled building parts initially used for our pilot project can only be recommended for small projects and when dismounted building parts are already available.

2.5.2 *Improvements*

The preferred variant is that of an intermediary site in which the dismounted building parts are stored, processed and examined without rush or hurry. In this connection, the necessary quality assurance could be regulated with the certification of the components. Should a building commission arise, the available recycled components could be transported from the intermediary site to the construction site. The advantage to this compared with a new part is the lack of a production phase. A recycled building part can be delivered immediately after just a brief processing time.

2.6 *The economical significance of the method of building with recycled components for the building trade*

One can say, in general, that recycling is especially profitable with building parts that have extensive production procedures. This could be an expenditure of craftsmanship on the one hand, producing high wage-costs through its great amount of work involved (e.g. historical building parts such as stairs, doors, etc. which are already successfully marketed via historical building-part stock markets). On the other hand, building parts particularly intense in terms of energy, such as the concrete prefabricated parts described in this contribution, are particularly economical. Concrete is especially intense in terms of energy due to its high proportion of cement which holds together the stone gradings. Approx. 80% of the primary energy expenditure for the production of concrete is in the cement. Approximately 50 to 55 litres of heating oil are needed for the production of 1 m^3 of concrete. The reuse of concrete prefabricated parts requires, on the other hand, only 2.6 litres per m^3 of "panelling." Converted to the realised pilot houses, this means that 4500 l to 6000 l of the equivalent of heating oil per house are saved through the use of concrete recycled components. This is one of the reasons why reuse in the area of building-part production is already today 50% cheaper than a comparable new concrete building part. This advantage will become even greater with continued energy price increases.

When building with recycled building parts, the cost advantage sinks by 26% compared with the usual massive construction method. These were the experiences gained with the pilot houses. The cost advantage especially shrinks because the recycled building parts were not planned for reuse. New construction measures were required for this that had not been tried on the market often led to compromises. Moreover, the usual new-building tolerance of new prefabricated parts of +/- 5 mm could not be attained. In the pilot projects, one must work with tolerances of the location construction of +/- 20 mm, which resulted in somewhat higher costs.

2.7 *The ecological advantages of recycling compared to new construction*

Alongside the economical advantages, especially influenced by energy and raw material prices, the ecological aspects especially speak out in favour of the use of building parts.

The recycling of building components in the building trade is especially significant in terms of saving raw material resources and energy when dealing with building materials with a long life and high degree of energy expenditure. Figure 1 makes clear the significance of the building carcass with regard to material and energy currents. E.g. 85% of the material mass is concentrated there. Figure 2 shows an ecological-balance comparison of a reused concrete prefabricated part with different recycled concrete, new concrete and masonry. The comparison with recycled concrete is particularly interesting. A clear advantage is recognisable in the primary raw material consumption, especially in mixture 3 in the approx. 50% recycled stone gradings. The energy values, on the other hand, show no improvement over the new concrete.

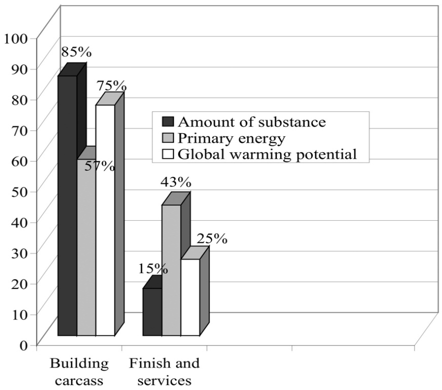

Figure 1. Comparison of carcass and finishing of a typical row-house in massive construction (sand-lime masonry, concrete slabs, ETIC) according to the German regulation for energy saving in buildings, simple design. The amount of substance, primary energy and the global warming potential in relation to the gross storey area are compared. The data are based upon our own calculations with the software LEGEP.

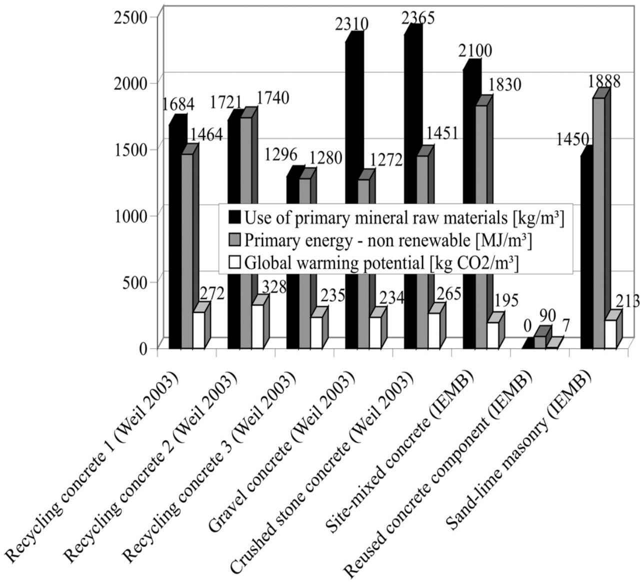

Figure 2. Ecological-balance comparison of the production (up to the factory gate) of a cubic metre of building material of new materials, recycled and reused materials.

This is above all due to the cement content of the mixtures, which tend to be somewhat higher in recycled concrete than in new concrete. The cementing material holding the stone gradings together primarily determines the ecological consequences. Since this binding remains when it is reused, the ecological balance for the building-part recycling is all the more advantageous the more energy-intensive the adhesive is.

3 PILOT PROJECTS

Since the recycling construction method was conceived from the very outset as a practical alternative for small-part apartment construction, a prototype was built in the TUB test hall at the beginning of the pilot programme. The test building was made of interior walls and prestressed concrete slabs of the type WBS 70 and provided with a variety of construction details which were needed for the pilot projects to be realised subsequently. The adaptation of the component geometry through sawing procedures, component strengthening, processing of damages and connecting technique amongst the components are especially notable. Until the beginning of 2007, 9 small houses could be realised in the recycling construction method being introduced through private initiatives. Several buildings will now be shown as examples.

3.1 *Prototype at the TU Berlin*

Figure 3. Processing of the demounted components with a concrete saw.

Figure 4. Test building after completion in the test hall of the TU Berlin.

Figure 5. The test building after being moved.

The test programme comprised the construction of a flat roof from shortened and whole slabs, the realisation of a high-pitched roof out of diagonally sawed walls and shortened slabs. The walls were made of both whole and cut components. The connections were made with demountable heavy-lift dowels. The building was dismounted after the test phase. Since 2006 a Berlin architecture bureau has been using the prototype as an exhibition pavilion.

3.2 *Pilot house in Mehrow near Berlin (Architecture bureau CONCLUS)*

The first pilot project in Mehrow was occupied in 0ctober 2005 (200 m² living area).

The construction method of the prototype studied before was realised. The slab and wall components were supplied by a donor building 8 km away. Demounting, processing and remounting took place “just in time,” within 12 days. The façade was covered with an external thermal insulation composite system (ETIC). Altogether, 118m³ of prefabricated concrete units were reused. This corresponds to an oil equivalent of 5900 litres.

Figure 6. Mounting of the building carcass.

Figure 7. Building carcass after completion.

Figure 8. Building after completion.

3.3 *Pilot house in Schildow near Berlin (Architecture bureau CONCLUS)*

The second pilot project in Schildow consists of a main and subsidiary house (280 m² living area). The transport distance was 33 km. The special feature of the building is the sattle roof, built entirely out of recycled concrete components. The facades were covered with an ETIC. Altogether, 245 m³ of prefabricated concrete units were reused. This corresponds to an oil equivalent of 12.250 litres.

Figure 9. Behind: Building carcass of the main house.
Front: Foundation of the subsidiary house.

Figure 10. Building carcass of main and subsidiary houses completed.

Figure 11. Animation of the finished building.

3.4 *Pilot house in Berlin-Karow (Architecture bureau CONCLUS)*

What is special about the pilot house (180 m² living area) is that recycling components were also used for the walls. Through this, higher spaces could be realised. The components had to be transported 23 km. Altogether, 91 m³ of prefabricated concrete units could be reused and 4600 litres of heating oil saved. This building was also provided with an ETIC. It was occupied in October 2006.


Figure 12. Building carcass.

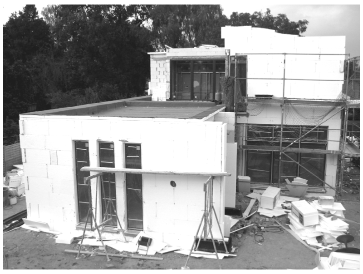
Figure 13. Installation of the ETIC.


Figure 14. Building after completion.

4 CONCLUSION

Recycling of building units is an alternative variant for a kind of construction which protects resources and saves energy. Especially long-living, durable, energy-intensive building materials, such as concrete, can be kept in the life-cycle longer through recycling. Prefabricated constructions are the prerequisites for constructions necessarily capable of being taken apart. As before, quality assurance and the marketing possibilities of building products are to be adapted to recycling systems. The economical components are responsible for the successful dissemination of the concept. The savings in costs of 26% in the case of optimal application in the building carcass area offers a lucrative complement to new building methods. This depends on several courses to be set, however. Alongside the logistics, back-building and remounting plans must be combined with each other; legal construction regulations and financial aspects must be improved. In this connection, the state is also asked to assume a leading role. Through the not inconsiderable support of back-building plans, for example, there is the possibility of providing motivation for the housing companies to occupy themselves with the possibility of a reuse of building units, through the differentiated support of demounting on the one hand and conventional demolition on the other hand. Construction methods capable of being demounted and reused should be developed and applied in the future.

5 REFERENCES

Asam, C. & Herr, R. & Kerz, N. & Vogdt, F.U. 2005a. Material- und Produktrecycling. In: Bauphysikkalender 2005. p.676-717. Berlin. Ernst & Sohn. ISBN 3-433-01722-0.

Asam, C. & Biele, H. & Liebchen, J. 2005b. Endbericht zum Forschungsprojekt: Untersuchung der Wiederverwendungsmöglichkeiten von demontierten Fertigteilelementen aus Wohnungsbautypen der ehemaligen DDR für den Einsatz im Wohnungsbau. Fraunhofer IRB. ISBN 3-8167-6954-3.

Hillemeier, B. & Spaethe, G. & Trätner, A. 1994. Abschlußbericht BI5-800192-2. Bauzustandsermittlung und Schadensursachenforschung an einem zum Abriß vorgesehenen Plattenbau. Auftraggeber: Bundesministerium für Raumordnung, Bauwesen und Städtebau.

Mettke, A. 1995. Wiederverwendung von Bauelementen des Fertigteilbaus. Traunstein. Plottner. Umweltwissenschaften. Band 5. ISBN 3-89367-054-8.

Spaethe, G. & Kießling, W. & Schulze, D. 1993. Gutachten. Voraussetzung zur Realisierung von Dachausbau- bzw. Dachaufbauvorhaben bei industriell vorgefertigten Wohnbauten im Land Brandenburg. Auftraggeber: Ministerium für Stadtentwicklung, Wohnen und Verkehr, Brandenburg.

Vogdt, F.U. & Kießling, W. 1998. Erfassung und Katalogisierung der nach einer Demontage für die Wiederverwendung relevanten Fertigteile der DDR-Plattenbauten. IEMB-Bericht 1-20/1998. unveröffentlicht.

Weil, M. 2003. Ressourcenschonung und Umweltentlastung bei der Betonherstellung durch Nutzung von Bau- und Abbruchabfällen, Dissertation an der Technischen Universität Darmstadt, Fachbereich Bauingenieurwesen und Geodäsie.

Guidelines for a good practices manual on sustainable construction

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ABSTRACT: Why a manual for good practices to Sustainable Construction? To reflect about good practices that can be applied to the Construction Sector. This manual will be an important tool to all deciders at construction level.
It's possible to construct in a sustainable way using materials and technologies that improve living conditions without destructing the environment. What sustainable construction aims is a careful selection of materials and technologies to be used in construction with minimal lost, promoting conscious and sustainable changes in all the building life cycle.
The implementation of sustainable buildings is fundamental to the wealth of our planet and our self. It´s possible to promote the Sustainable Construction without increasing construction costs trough technological development and market laws.
From the analyses made it's possible to conclude that is necessary to rethink the construction sector activities, in and integrated holistic way, trough a qualitative way of change, towards Sustainable Construction.

1 SUSTAINABLE CONSTRUCTION AND ENVIRONMENTAL IMPACTS

All the impacts it's important to refer the waste production, energy consumption, CO2 emissions and natural resources consumption.

In construction phase it´s consumed about 50% of the natural resources, 50% of waste production, around 40% of energy consumption and 30% of CO2 emissions are verified in construction phase, in industrialize countries (corresponding to 20% of the total energy in Portugal).

The construction cycle is namely an open cycle, functioning between a source (the nature) and a sink (again the nature). The construction extracts from nature the materials needed to construct (sand, water, etc.) and gives back to nature the waste from the production of other materials (cement, paints, etc.) and from the usage of buildings (atmospheric pollution) and, in the end, the demolition products.

In sustainable construction this cycle is closed, existing several closed cycles, namely:

- The building's reuse, with small changes
- The building's reuse, totally rehabilitated
- The building's components (deconstruction) reuse or the reuse of construction materials (in other From the several sectors of activity in our society, the construction sector, not only in the operation phase (building use) but also considering the construction phase, has several environmental impacts that imply responsibilities and the conscience at the environmental level.
- From buildings or roads

One of the main advantages of sustainable construction is the improvement of energy efficiency with the reduction of CO_2 emissions.

The urban sustainable conception (soils use planning) contributes to the reduction of the urban sprawl and natural habitats and biodiversity depletion. The urban environment integrated management should promote sustainable policies on soil use that avoid the urban sprawl and the reduction of impermeable soil, namely in the promotion of urban biodiversity and the sensitization of urban citizens.

The soil protection must be approached trough industrial space rehabilitation and reuse and by spatial planning and economy, having in mind the reduction of impermeable soil and guarantying the rational use of them.

The sustainable urban transport planning will contribute to reduce atmospheric pollution and noise and stimulate the bicycles use and walking, which will allow a health conditions improvement. Sustainable construction methods are a contribution to promote comfort, security, and accessibility, reducing health and atmospheric pollution impacts in the interior and the exterior of buildings, namely by suspension particles from heating systems.

At the social/urban context we should consider that buildings serve to receive people and a good connection between them should be stimulated. That can begin by satisfying the users expected quality level, by understanding what those quality expectations are. In order to do it people's participation in quality parameters definition it's crucial to guaranty a good functioning.

By what has been said, at any project conception phase a special attention must be taken in each sustainability vectors: environmental, social and economic. Without them the project won't be viable. Although, to analyze and monitor all construction phases it's necessary to define all objectives and targets, which must be reached by economical performance and social environment. That's why a building monitoring system should be implemented.

2 GOOD PRACTICES AT ENERGY LEVEL

This paper objective is to reflect on good practices to be applied at construction sector, in order to respond the sustainable development challenges, presenting sustainable solutions guidelines associated to building life cycle activities. These guidelines should be a base to a sustainable construction good practices definition.

These good techniques and tools application are transversal to all construction sector, if the needs and conditions to those applications where identified. This implies a previous study about the building needs (energy, water, materials, etc.), revealing the planning stage importance.

In order to contextualize sustainable construction good practices, there will be identified some action vectors, grouping measures that can be applied, namely:

- Planning
- Energy and gas emissions
- Water and wastewater
- Materials, waste and quality
- Indoor air
- Social aspects (comfort, relation with users and environmental promotion)

These vectors will be analyzed in a bigger detail in the next text.

2.1 *Planning*

Any activity's planning is determinant to the inclusion of sustainability measures. It´s necessary to previously understand the project's characteristics, in order to establish objective and adequate measures.

In the planning phase is determinant to define the building's characteristics that can influence his environmental performance, such as:

- Occupation type;
- Activities that are going to be developed in the building;
- Occupant's characteristics and needs, etc.

The next step is to analyze the construction local, in aspects like:

- Localization;
- Local parameters, like the soil type, type of occupation, climate, orientation, solar exposure, rain water affluence, etc.;
- Localization in terms of other interest areas to future occupiers.

These two characteristics groups (project's and local) are determinant to define sustainable measures. This planning phase is important to the other vectors of action that are defined bellow, like energy and water consumption and comfort. So, it´s important to define the local potentials to the implementation of passive energy measures and the use of renewal sources of energy, that are directly connected with occupiers internal comfort and also to the reduction of water consumption, trough the use of rain and reused water.

Before these aspects is the local to build selection that, anytime as possible, should be also a target of environmental parameters that contribute to construction impacts in the local to intervene. These evolve questions like the reduction of impermeable soil, natural habitats affectation, urban sprawl, etc., to each it's crucial the urban intervened soils reuse and the building rehabilitation.

2.2 *Energy and gas emissions*

The energy consumption in buildings is our day's one of the most concerned aspects to sustainable construction, due to the increase of these consumption in these sector (22% of total energy consumption in Portugal is verified in buildings (*Balanço Energético de Portugal*, 1999), in Pinheiro, 2006), mainly because the energy inefficiency that characterize it.

Buildings should be projected in order to improve the energy efficiency, reducing the effective needs of energy, and using, every time as possible, renewal sources of energy.

The passive energy measures are determinant to reduce the energy needs in the use stage, they are related to the use of solar energy to building heating, trough the construction strategies and conceptions.

- Appropriated heat insulation;
- Appropriated orientation (according with projected utilization);
- Appropriated dimensioning of windows and double window usage; etc.
- The use of passive solar energy allows the utilization of solar energy, trough the sun incidence, to building heating. The main advantages are the low cost of most solutions referred, solutions that can reduce 40% of energy consumption.

Relating to energy consumption to building functioning, it's important to refer the utilization of renewal sources of energy, efficient energy consumption systems and decentralized energy production.

Solar and wind energy are the most used renewal sources of energy.

The production of energy from wind has to be analyzed previously trough wind monitoring. The kinetic energy, resulting from wind, can be transformed in mechanical energy, trough a wind engine, or electrical energy trough wind turbines or wind turbine generators.

Sun is another potential source of energy to Portugal. There are two forms of solar energy usage, trough the passive way, already referred, and the active away, transforming solar energy into thermal energy (using sun collectors) or into electricity (using photovoltaic collectors).

The principal applications of thermal solar energy are the water heating, to sanitary usage. The electrical energy is one of the most promising future sources of renewal energy. The almost absence of pollution is one of the main advantages of this source of energy. Although, one of the main limitations is its small efficiency, this means a small conversion of solar energy in electrical energy.

It´s important to refer that is possible to combine several types of energy, like wind and solar energy, as it can be seen in the next picture.

In alternative to big energy centrals and high tension distribution nets, the decentralized energy production is getting more reasons to become one of the future technological solutions to energy applications, like micro-generation, cogeneration and trigeneration.

These concepts have the same principles: the decentralized energy production, using simultaneously thermal and electrical energy. They have different definition due to different powers installed, and the trigeneration by producing electricity, heat and cold.

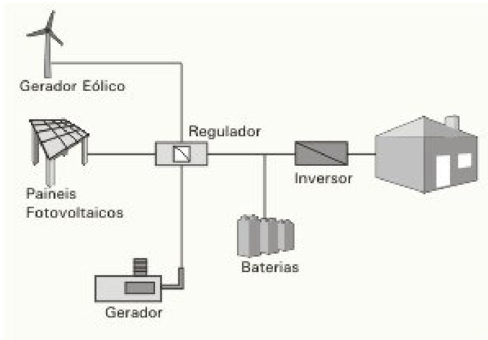

Figure 1 - Integrated use of solar and wind energy technologies (Santos, 2007)

This new technologies use mainly natural gas, but they can work with renewal sources of energy (like sun and wind), with less (or any) gas emissions. With these technologies it's also possible to use the heat released in electricity production, using in a more efficient away the energy resources.

Cogeneration is then defined as the simultaneous production of mechanical and heat energy, from a system that uses only one source of energy. This primary energy, transformed in final energy, can have different origins.

Beyond the referred measures of passive performance and the utilization of renewal energies, mainly in decentralized production systems, it´s also important to promote the use of better energy rationalization technologies. These can be applied at the energy equipments level, pumping systems, acclimatizing and ventilation systems, in the recovery of thermal energy and lightning. To these systems it's important to apply measures to: select equipments of high efficiency, to respect the equipments maintenance needs and analyze the project needs and the several solutions that can be applied, selecting the most sustainable ones. For example in lighting systems the natural lighting should be optimized, trough direct utilization by windows or trough other indirect ways, like sun pipes, etc., selecting high efficiency lights to guaranty the adequate lightning levels.

The referred measures optimize building energy consumption, reducing the utilization of fossil sources of energy, and so reducing gas emissions. The CO_2 it's the most important gas emission, because its greenhouse potential. However, other gas emissions are also important, like SO_2 and NOx, equally associated with fossil combustion, which are relevant, for example, in acid rain.

2.3 *Water and wastewater*

The water consumption in building, mainly potable water, it's also the cause of several environmental impacts that cause the degradation and contamination of water resources, by the consumption and the production of contaminated wastewater. The water consumption by Portuguese population is around 7% of total consumption (INAG, 2001). It's important to say that, at the distribution level, the lost value is very high and also that around 80% of the water that is consumed returns like wastewater. These are important considerations that enforce the need on establishing measures to reduce water consumption and improve the consumption efficiency.

The strategy should consider the reduction of water consumption, using rain and wastewater, and also the reduction on wastewater recovery and treatment systems pressure.

Some examples of measures to reduce water consumption are:

- Flow reducers on tap;
- Temporizing valves on WC tap;
- Thermostatic valves to showers;
- Double charge WC;
- Humidity sensors in green areas;
- Adapted and/or autochthones species, that reduce the maintenance and water needs in gardens.

These measures can reduce the water needs, both in internal and external areas. However, to the remain needs, that also don't need potable water, some measures can be established, like:

- Use of rain water: through a rain water recovery and storage system, using this water in WC, gardens and outside spaces;
- Implementation of a wastewater treatment and reutilization system, using wastewater in toilets and green areas.

In a integrated way these measures allow a reduction on water consumption and also on wastewater production, reducing the pressure on municipal treatment systems. However measures to locally treat wastewater should also be included, such as:

- Dry toilets;
- A separation system to grey and dark wastewater;
- A recovery and treatment system in the building area, like biologic systems to WC, plants systems, etc.
- All these measures can minimize these vector impacts, by reducing water consumption and minimizing the wastewater production.

2.4 *Materials, waste and quality*

The construction sector is one of the most intense one's in the consumption of materials. Ngowi (2000) says that the building construction is responsible, for the consumption of 25% of wood and 40% of aggregates (stone, sand, etc.)(in Bragança et al, 2006).

The material consumption impacts are extended and very complex to analyze. In many cases the materials become from places far away from the building and can have large impacts related to its fabrication, transformation, transport and distribution, that, for example, extremely increases the materials embodied energy. Other impacts easier to identify are related to natural resources degradation, dust, etc.

The materials consumption has also consequences at the waste production level, since a large parcel of the consumed materials are then released as waste and also because the small recycling rate.

Other aspect to have in mind in the selection of materials it's the quality and functionality of the constructed space. To respect these principles, sustainability parameters should be included at materials level, that allow:

- Minimal utilization of materials;
- The use of materials with small amounts of embody energy, selecting materials coming from small distances;
- The use of recycled materials, or materials with potential to be recycled;
- The use of ecological materials, environmentally certificated, and non toxic.

Besides this aspects there should be considered the utilization of construction techniques that allow the materials inclusion the most adequate way, such as:

- The construction materials and techniques used should permit the deconstruction and recycling of the building components, at is end of life;
- To guaranty the quality of materials and components, namely, with pipes and electrical installations, ensuring the building's quality and durability;
- To ensure the possibility of internal and external space adjustments, in response to its users needs during the building life time, namely by changing areas, removing walls, etc. To allow these adjustments, the constructions of walls, the pipes and electrical installations, etc., should be designed to be flexible and functional;
- The concentration of pipes and other electrical installations, for repair and maintenance reasons.

The parameters described below are a first step towards the reduction on waste production, since they minimize the material needs, enforce the reuse, by construction methods that allow deconstruction in place of demolition, and also because they promote the materials recycling.

Besides these measures, to promote even more the waste reduction it's important to enhance the reduction, reuse and separation of waste, in the construction and use stages. The hazard wastes are the most important ones and, to promote sustainability at waste level, there should be made contracts with legal entities to recover these wastes (kitchen oil, lamps, etc.).

2.5 *Indoor air*

The aspects related to air quality inside buildings are extremely important, because we spend about 90% of our time inside buildings and a bad air quality can be the cause of several diseases to the occupants.

The main impacts coming from a bad air quality in buildings are felted directly by their occupants, normally related with the Sick Building Syndrome, associated to air contaminations such as: dust, legionella, tobacco smoke, volatile organic compounds (VOC), heavy metals, etc. The health problems caused by these components can be allergies, breading problems, sickness, etc., and even cancer.

It's possible to establish tree class sources of contamination:

- Internal sources: materials and activities;
- External sources: infiltrations of contaminated air from the outside;
- Bad air circulation in the building (ventilation and renovation problems).

This source of contamination shows the planning stage, materials and construction methodologies importance: a good planning, with a good materials, construction and organization (of the building) analyses can avoid these toxic compounds presence, guarantying the life quality of their occupants. It´s also clear that the environmental aspects of buildings directly interfere with its occupant's life quality, and that sustainable construction doesn't only aims the minimization of environmental impacts, but also wants to establish a harmony between built space, environment and health and well-being of its occupants.

To minimize the internal sources of air contamination, one of the main aspects to be consider is the materials selection, without components that can be harmful to health, like VOC, asbestos, CFC/HCFC, heavy metals, radon, etc. The main materials to be careful at are insulation, paints, glues, wood, etc. For another hand it's important to guaranty and adequate insulation of areas where activities that release pollutants occur.

The reduction of contaminations due to external sources is related to the correct location of outside points of air extractions, insulation of possible areas with contaminated air (garage, etc.).

Although the aspects referred, it's very important to guaranty the adequate renovation of inside air, avoiding the concentration of hazards substances.

Other important aspect is the correct equipments maintenance, namely air condition devices, responsible for bacteria and fungus, namely legionella.

It´s import to refer that after construction, mainly after the finishing phase, it's important to guaranty the internal space correct ventilation before its occupation, releasing the hazards compounds from materials, more intense after its application.

2.6 *Social aspects (comfort, occupants relation and environmental promotion)*

Like cited before, the construction of a sustainable building must integrate environmental, social and economic aspects, considering the potentialities and best measures that can be applied to each project.

The social aspect is very important since buildings are constructed to be used for people and so their needs and comfort should be guaranteed, and also because a building sustainability can only be reached if their users have sustainable behaviors, making use of the potential that a building constructed to be sustainable offers.

By other perspective, to ensure the users satisfaction it's important to have a functional and adaptable space, in and out the constructed areas. To achieve this, it's important to allow the adaptation of thermal, acoustic and lightning comfort and also in physical aspects like changing areas, removing separations, etc.. The internal and external space, mainly in common areas, should also be developed in order to promote users interaction, in leisure, cultural, etc. activities.

Finalizing, it's also equally relevant the environmental promotion, which is a crucial element to ensure a continual good environmental performance, during all building utilization. All important environmental issues that can be a target of environmental education to users must be identified, including simple aspects like good practices (waste separation, reducing water consumption, etc.) and aspects related with good building functioning (equipments and building instructions, functioning and maintenance, etc.). It's also important to establish a monitoring methodology that can control, verify and continuously improve all environmental measures that can be combined in an environmental management system, in a more integrated perspective.

3 OBSTACLES TO SUSTAINABLE CONSTRUCTION AND CONCLUSIONS

The present paper aimed to be an approach of sustainable measures that can be applied do construction, in order to promote sustainable construction.

The main impediments to sustainable construction are bureaucracy, the difficulty achieving some market technologies and the waiting time needed to use them. Another problem can be some economic increase, in terms of payback time, which is mainly due to a disintegrated analysis, because, if considering all life cycle, sustainable construction is certainly liable.

Promoters must be encouraged to analyze construction in a sustainable perspective, because in our days we cannot say that there aren't mechanisms or laws to the application of sustainable construction principles. A proof of this fact is the current European directive that imposes an energy certification to all new buildings.

We hope this work can show the feasibility, availability and, in many cases, the simplicity of most sustainable construction measures, to all construction stakeholders.

In conclusion, to promote sustainable construction, we should consider all the sustainable potential at each project, in order to obtain:

- A better local integration, considering climate and other local aspects;
- Reduce the natural resources degradation (by consumption or pressure);
- Improve the users comfort and sustainable behavior.

Sustainable construction is a concept possible to realize, without significant costs, achieving not only a minimization of construction environmental impacts, in all life cycle stages, but also upgrading building's quality and comfort.

This paper attempts also to demonstrate that sustainable construction needs the participation and cooperation of all parties evolved in construction sector: sustainable construction doesn't stops when responsibilities stop, doesn't end when contracts end, it's, in contrary, a continuous process, that must be considered at all stages of its life cycle, by all parties evolved in every step.

4 REFERENCES

Bragança L.; Mateus R. (2006). Tecnologias construtivas para a sustentabilidade da construção. Edições Ecopy. Porto, Portugal.

Brundtland Commission, 1987, Our Common Future (The Brundtland Report), World Council on Sustainable Development (WCSD), Oxford: OU

Estratégia Nacional para o Desenvolvimento Sustentável 2004 – acedida em http://www.estrategiadelisboa.pt

Pinheiro, M. (2006). Ambiente e construção sustentável. Instituto do Ambiente. Amadora. Portugal.

Primeiro Congresso sobre Construção Sustentável, 2004. Leça da Palmeira

Santos D., Isabel (2007), Manual de Boas Práticas de Construção Sustentável, Trabalho de projecto final de pós Graduação em Planeamento e Projecto da Construção Sustentável, FE - UCP

Sustainability in lightweight modular construction for housing

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ABSTRACT: The central issue of the research synthesized in this paper is how the building industry sector could develop some resource management strategies which can close the materials cycle. In order to do this, the possibilities of industrialized lightweight architecture were analyzed under the physical demands of the "strong" sustainability. Light volumetric modular building type was studied because it possesses some important characteristics: a) Industrialized construction permits to work whit a limited number of materials and to control related amounts of resources and waste, b) This system has developed an innovative commercialization form. Renting modules come back from building to factory after use allowing reuse, refurbishment and recycling without waste generation. c) Modular units are available globally without technologies inconveniences, d) They are adaptable to different climates and regional conditions and, finally, e) Similar building systems can take advantage from the strategies developed.

1 TOWARDS CLOSING THE MATERIALS CYCLE

1.1 *From a physical point of view*

The Earth is an open system in terms of energy yet a closed system in terms of materials, and it is a lot easier to convert material into energy than it is to convert energy into material. Therefore, material must be effectively controlled in order to ensure proper management of resources and waste matter.

Living organisms need to break down energy and material to keep them alive, and the only way to avoid this process causing entropic damage to the Earth is by using renewable energy from solar sources. This would permit a complete recycling of materials, in a way similar to photosynthesis, the process that allowed the biosphere and the human species to develop (Naredo, Valero).

Can we continue to use non-renewable resources? Human life depends on the 'stock' of material found in the Earth's crust. The question is how natural energy sources can be used to close the cycle of material, allowing waste to convert back into resources, avoiding damage to the Earth's crust due to waste contamination and diffusion of raw material.

Economically speaking, the value of goods (in this case, non-renewable energy) is determined by the cost of extracting the material, not by the cost of replacing it. This explains why extraction is the preferred method to the cost of recycling (an oversight that we will end up paying for), making the civilized world's industrialized system of production less and less like that of the biosphere, which in contrast is sustainable (Cuchi).

There are two clearly different ideas of sustainability. Weak sustainability was developed as a result of the standards of today's economic climate, and strong sustainability was developed on the principles of thermodynamics (physic's version of economics) and ecology (nature's version of economics). The former type of sustainability relies on the Earth's natural stock of capital, supposing the replacement of the stocks by man-made products, and the latter type of sustainability recognizes that the Earth's natural stock of capital can not be replaced by a manufactured material and thus, efforts must be made to avoid the deterioration of these sources (Naredo, Valero).

For this, it is necessary to establish an institutionalized framework and a social conscience that will promote renewable production and recycling as opposed to extracting material and transporting it long distance. These are key issues that must be considered in order to promote the management of closing the materials cycle.

1.2 *From an industrial point of view*

The industrial metabolism is an integrated system of processes that converts raw material and energy into waste. Production is not regulated in itself; it is directly influenced by human factors such as the workforce, and indirectly influenced by the rate of consumption, which in turn determines demand. In a decentralized economy, the industrial system is regulated by the balance between supply and demand of products and work, by means of the price of the product. The economic framework is, in essence, the regulatory mechanism of the industrial metabolism.

One major difference between biological and industrial metabolisms is illustrated when comparing the life cycles of material or nutrients. The water cycle and nitrogen cycle are examples well known to scientists, yet while they are closed cycles, the industrial equivalent is an open cycle. Generally speaking, the industrial metabolism fails to recycle its nutrients. The process begins with high quality raw material that is extracted from the Earth's crust (such as minerals or fossil fuels), which is returned back to the earth in a state of deterioration, thus increasing entropy (Ayres, Ayres).

The cycle of materials is generally seen as a system of compartments containing stocks of one or more nutrients bound by certain flows. The system is closed when it does not need any external supply, like the planet as a whole, for example (except for the phenomenon of meteorites). The system starts to become a closed cycle when stocks of each component are constant or do not significantly vary. This implies that there must be a balance between what goes into and comes out of each compartment.

The closed cycle of materials can sustain itself indefinitely thanks to a continuous flow of exergy. In brief, exergy means the minimum amount of useful energy which is necessary to make a system from its primary elements when they are in a dead ambient. Exergy becomes usual as a cost measure in a sustainable analysis. This is directly determined by the second law of thermodynamics, which states that global entropy is an increasing, yet irreversible process. The exergy would be used simultaneously if it was not conserved, and consequently the closed cycle would be able to sustain itself for as long as the flow of external exergy lasted.

The open cycle however is unstable and unsustainable. It either stabilizes or collapses against the thermal equilibrium of each of the flows until all physical and biological activity comes to a halt.

The industrial metabolism is normally an open cycle. Hence it can synthesize in a systematic sequence the extraction of raw material and the production of waste. Yet this system possesses a hypothetical number of intermediary cycles that would allow the system to be closed.

What was until recently considered as waste can nowadays be considered as raw material. In the last few years, various companies such as carpet manufacturers have developed new technology that allows their factories to be powered by recycled raw material. This technology replaces the linear production process that has been in use since the industrial revolution (extracting unlimited quantities of raw material and converting it into contaminated waste). Instead it is a cyclical process similar to that of the biosphere, which does not create waste, but raw material that can be used over and over again to manufacture brand new products. Nylon coating can be recycled into new nylon thread, and polyester casing into new polyester fiber. An example of this development is Interface, the world leader carpet producer; it has created a biopolymer derived from natural resources such as plants. It is 100% recyclable, but also compostable and can be used to make a single material carpet. Some of the Interface factories are changing our energy sources to renewable energy ones (Anderson).

Another method of closing the materials cycle is by using eco-industrial systems. These are areas, for example an industrial park or a region, where all material used is collected then recycled back into the system. In this way the system only consumes renewable energy from outside, and produces a service, not a product, to be sold on the market (this is made possible by renting instead of selling the service). Perhaps the most famous case of this type is the Kalundborg industrial park in Denmark where, in brief, residual heat from an energy plant and a petrol refinery was used to heat greenhouses. The industrial waste was converted into products such as fertilizer or building material.

In an eco-industrial system, four basic conditions permit the material cycle to be a closed cycle. Firstly, the operation must be large scale to allow for the interchange of diverse material, and include a company that will ensure large scale activity, such as an exportation company. Secondly, there must be a large company in the local area that would be able to absorb the waste produced by the first company, after having converted the waste into usable material. Thirdly, there must be other specialized 'satellite' companies to use the rest of the first company's waste, either as raw material or as marketable goods. Fourthly, and most importantly, a mechanism needs to be put in place that will ensure long-term technical co-operation between participating companies. The organization with the responsibility of ensuring such conditions would be the exportation company, or an organized group of companies, or even a public agency.

2 HOW CAN THE MATERIALS CYCLE BE CLOSED IN ARCHITECTURE?

When it comes to closing the material cycle, there are many advantages associated with industrialized construction systems as opposed to the traditional ones (which normally have an on-site factory, intensive labor and non reversible joints).

Modular co-ordination, standardization, mass production and control of the manufacturing process all facilitate the streamlining and optimization of the use of resources. Such characteristics also permit the reduction, revaluation and reuse of waste matter. Industry is technically capable of converting left over and faulty material into new raw material or components, and this is important to the strategy of revaluing waste, and converting it into usable raw material.

Industrialized construction normally uses both heavy systems (500-2000 kg/m^2, usually concrete) and light systems (approximately 150-500 kg/m^2, wood, plastic or metal). Each type uses different amounts of material and energy resources. Heavy systems need larger quantities of on-site materials and fixed weights for larger structures, and also require the means of transport and assembly suitable for heavy loads. Light systems can use smaller amounts of material, and therefore require transport and assembly suitable for light loads.

The use of light systems can therefore give rise to dematerialization (or increase in the productivity of material resources), which is the second important strategy.

An interesting type of light industrial system is the modular 3D which is usually made of metal, and measures 2.44m (interior width), 2.6m (exterior height), and 6.01-12.02m (length), conforming to the standard ISO norm for transport containers. Modular units and reversible joints allow the buildings to be assembled and dismantled time and again, and also allow for changing the layout or function of the building. Therefore, the building's modular units can be reused at other times, in other buildings, and can also be used for partial restoration. This is the third strategy, deconstruction and reconstruction, (instead of demolition, the building can be rebuilt and taken down numerous times, until its modular parts are no longer fit for use.)

The modular 3D structure is generally made of two frames (floor and roof), and four columns made of tubes or cross sections of steel. Modular paneling, such as floor, covering, roof, insulation, woodwork and interior finish, is assembled onto the structure. The paneling is easy to assemble and dismantle, and component parts can be changed with ease. In addition, when the parts can no longer be used, they can be separated into their component materials. This is the fourth strategy; the substitution of materials (for example substituting polyurethane, PVC, and organic solvent-based paints for other non-contaminating materials that can be recycled.)

A final point to consider is that the marketing strategy for modular systems is based on leasing, rather than selling. In this way, the temporary and permanent modular 3D buildings can be leased from the suppliers, who will take care of assembly, maintenance and dismantling, and once finished with, the modular units are returned to the manufacturer. There are many companies in Europe who offer this service, for example Algeco, Balat, Bauart, Erne, Interlink, Yves Cougnaud. This leads to the fifth strategy, the three R's, repair, reuse and recycling (the modular components are sent back to the manufacturer, this proves to be technically and economically viable).

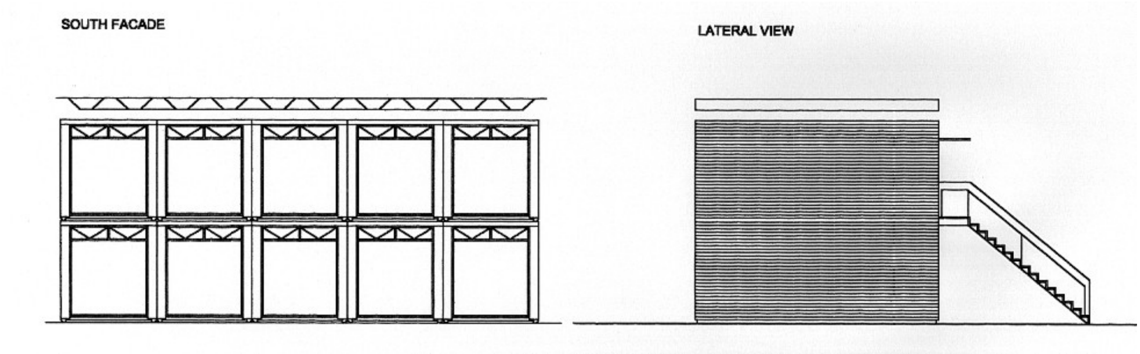

Figure 1. Typical lightweight modular units available in Spain.

3 WY BUILD BY STEEL?

The composition of modular 3D structures that are sold in Spain (eg Algeco, Balat, Yves Cougnaud systems etc.) is as follows; steel 105.4kg/m^2, wood 17kg/m^2, polyurethane 5.6kg/m^2, aluminum 20kg/m^2, paint 1.5kg/m^2, copper 0.3kg/m^2 (Algeco). Steel accounts for two-thirds of the total material weight, and is the principal area of study in this type of building system.

One can consider that there are three types of recyclable material. The first group is made up of materials that are economically and technologically compatible in question in terms of price and regulations. The second group is material that is not recycled for economic reasons, although technically recycling it would be possible. The third group consists of material that cannot be recycled due to economic and technological reasons. The majority of structural metal belongs to the first category of materials, and steel in particular offers many advantages over other types of metal when it comes to recycling (eg. magnetism for an easy separation process).

The technology to manufacture and use steel in construction is widespread, and it is globally available. This means that, in principle, a particular technological innovation constructed in steel could have an impact in many other parts of the world. Its structural capacity allows for the effective use of small quantities of material that can be reinforced using laminating streamlining and folding techniques.

Steel is one of the most recycled materials in the world, 350 million tones are recycled each year, and this recycling process dates back to approximately 100 years ago (IISI). Steel can be recycled many times over, without losing the quality of the material. From the fourth recycling process, embodied energy and emissions of CO_2, SO_X and NO_X gases from the steel produced from minerals reduces by between 25 and 30% (British Steel 1). Electric arc furnaces can use nearly 100% of the scrap metal to produce new steel, a process which in some countries is economically convenient to make several types of building pieces (ISSI). At the moment, about 80% of the scrap metal available is converted into new steel and there is still demand for a lot more because approximately a half of the world's industrial production is still derived from minerals (IISI).

Material that has been painted and galvanized can still be recycled. This will not affect the process, as the gases are either eliminated during melting, or turned into solid waste which can be separated from the recycled material at the end of the process. Galvanization zinc is usually recovered when recycling steel (ATEG). This is different for other metals, as once they have been covered, they cannot be easily recycled (eg some painted aluminum).

Approximately 95% of the total amount of steel used in a building can be recycled, thus the building can be leased for an amount of time, still as part of the structure. Like the modular 3D, many structural components and even completed steel structures can be leased for the space of time that they are required for, instead of being sold. In some cases the parts are designed to be assembled and dismantled, allowing for further use. An example of this type of building system is the Hangar Nº2 in Cardington Airport, which was relocated to the Building Research Establishment (British Steel 1).

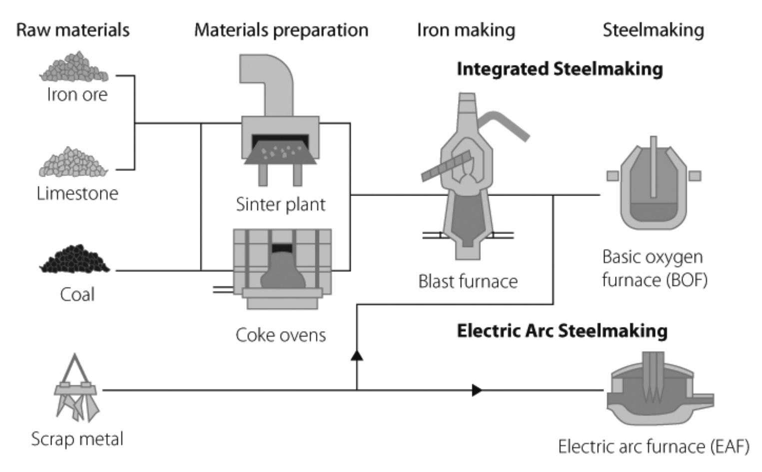

Figure 2. Basic oxygen and electric arc furnace production steel system

4 AN ENVIRONMENTAL ASSESSMENT APPROACH

Three types of houses were analyzed by using TCQ 2000 Environmental Management Module software developed for the Institut de Tecnologia de la Construcció de Catalunya, ITeC. First, predominant concrete structure and brickwork based (Conventional). Second, standard Algeco's modular unit steel based that are usually sold in Spain (Basic modular). Third, improved modular unit based on environmentally friendly materials modifications (Optimized modular).

Direct and indirect materials consumption, embodied energy and green house emissions of the construction phase were calculated for each type of building. First, all materials involved were accounted in order to determinate its weights in a representative square meter composition. Second, these materials amounts were converted to energy consumption and CO_2 gas emissions using the environmental information of the PR/PCT building database of the ITeC. Third, a similar process were followed in order to determinate the material intensity per unit of service (MIPS) for abiotic, biotic and water resources affected into the extraction and production stages, where Wuppertal Institute MIPS indicators were used.

The results chart shows that there are several gaps between Conventional, Basic modular and Optimized modular types. Synthetically speaking the last one reaches the smallest levels at each environmental impact effect considered but in order to evaluate the closing the loop condition a recycling potential and zero waste approach should be developed in deep.

Table 1.Environmental indicators for both conventional and modular construction at the building phase (basic modular is showed as reference).

	Conventional	Basic modular	Optimized modular
Building materials (kg/m^2)*	2.961 (285%)	1.038 (100%)	205 (20%)
Energy (MJ/m^2)*	6.987 (90%)	7.768 (100%)	2.721 (35%)
Greenhouse emissions (kgCO_2/m^2)*	672 (79%)	847 (100%)	143 (17%)
Total material requested TMR1 (kg/m^2)**	7.405 (232%)	3.193 (100%)	1.072 (34%)
Total material requested TMR2 (kg/m^2)**	23.777 (119%)	19.990 (100%)	7.435 (37%)

* ITeC building materials PR/PCT data base was utilised. ** TMR1: abiotic + biotic resources, TMR2: abiotic + biotic + water resources. Wuppertal Institute Material Intensity indicators were used.

In order to see how the optimized module house type can be affected for the different Barcelona climate conditions an indoor temperature simulation was done. Solar protection (textile screens on south exposed windows) and mass inertia (10cm thick concrete floor slab) building components were added to the initial configuration. By using Balanç (De Bobes, Tribó), dairy interior temperatures were calculated for winter and summer without both heating and cooling help. Analyzing them into the comfort temperature band (18-22ºC for winter and 24-26ºC for summer) it can be seen that heat peaks on winter and summer go beyond the maximum level. Conventional construction houses present similar cooling energy consumption areas. This is a frequent situation on several buildings like workplaces ones at Barcelona but in order to reduce them ventilation and mass inertia should be increased on module units.

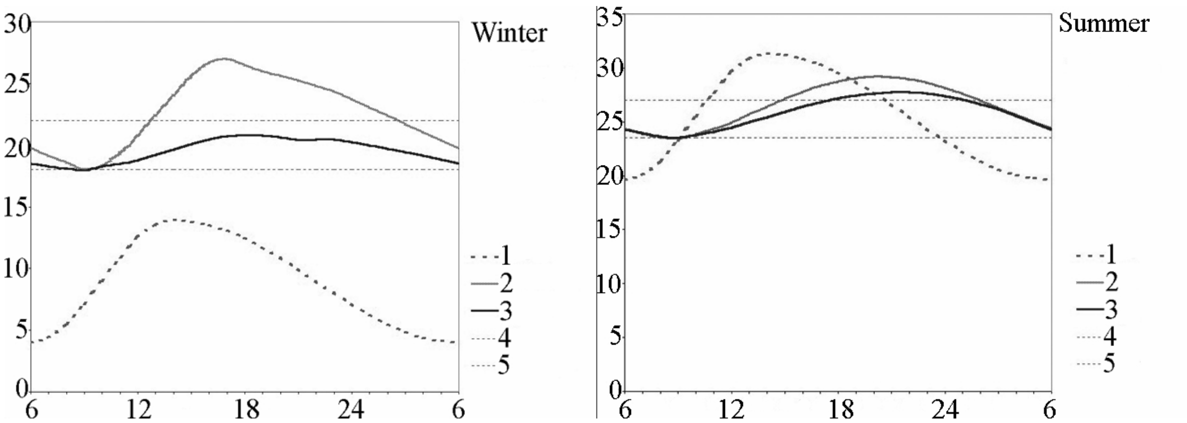

Figure 3. Typical one-day cycle of interior temperatures into the optimised modular house.
References: 1 exterior temperature, 2 sunny day interior temperature, 3 cloudy day interior temperature, 4 minimum level of comfort, 5 maximum level of comfort.

5 THE CASE OF THE VALLES SCHOOL OF ARCHITECTURE COMPETITION

In October 2001, the Technical University of Catalonia ran an open competition to extend the existing Valles School of Architecture.

One proposal was based on the same idea explained in this paper using light steel 3D modular components, in order to extend the school without any new impact on the environment. The design team was composed for Albert Cuchí, Albert Sagrera, Gerardo Wadel (architects), Anna Pagés, Isaac López (students in collaboration).

This proposal suggested the use of modular systems that are presently available on the market, and also proposed leasing the structure for 5 year periods. In order to do that an agreement would be reached with the supplier (Ormo, S.A., which is called today Algeco Spain) to gradually improve the structure, facades, roof, windows, which would create a new generation of more sustainable modular units.

From the point of view of materials, the proposal suggested the dematerialization of modular units, the revaluation of manufacturing waste and the substitution of contaminated or non-recyclable materials for other materials. Also, the deconstruction and separation of materials into their component elements, and the three R’s, repair, reuse and recycling were proposed.

From the point of view of use, the project suggested the reduction of consumption by using more efficient equipment, the collection of natural energy, the installation of thermal energy storage into the horizontal frame (British Steel 2), the refrigeration of naturally cooled air to protect from excessive heat gains in the summer. In this way the modular construction system presently in use would evolve, the cycle of resource material would be closed, and auto-sufficiency of energy resources would be maximized.

The project was praised by judges for its ‘didactic spirit, and the sheer effort that was made to establish the basis of an architectural system which respects the environment’ (Act).

In spite of this, the proposal could not awarded first, second or third price as the university management chief objected to the system of leasing. Unfortunately, the competition guidelines did not mention this expressly, yet it was interpreted that the new building had to be purchased and the leasing system could be objected from other competitors.

A few years ago, on 2004, a similar modular lightweight building system called Spacebox began to be used at some Netherlands's universities like Utrech, Delft, Eindhoven, and Hilversum, for student housing accommodation (www.spacebox.info).

Figure 3. A view of the Vallès School of Architecture proposal.

6 THE CASE OF THE INCASOL COMPETITION FOR YOUNG PUBLIC HOUSING

Few years ago the Incasol (Institut Català del Sòl), an institution of the Catalonia Government which promotes public housing, organised an open competition calling both architects and builders to show together their last technology innovations developed in the previous years as a part of their regular works.

A management idea based on the 3D lightweight modules was presented by Albert Cuchí, Albert Sagrera, and the author of this paper in collaboration to Algeco Construcciones Modulares, S.A. (modules manufacturer), obtaining a special recognition from the jury for its environmental characteristics.

From the sustainability point of view this was a closing the loop strategy for renting housing, making possible to leave behind the traditional building concept that only can consider them as a real state goods.

The project presented to the Incasol competition was based on a lightweight modular building system witch can be assembled and dismantled entirely without any important waste generation nor materials decreasing, in order to be transported and assembled in another place (reuse), to be returned to the modules factory (refurbishing), or to be given to recovering materials industries (recycling).

The central concept was focused on the change that the traditional public promoter's role should experiment in order to reduce the environmental impact of the renting housing they habitually build and manage.

To assure the described conditions it is necessary that all resources involved can be maintained into the industrial management avoiding the usual waste generation. Some traditional promoter's tasks like construction, maintenance and finally demolition, have to pass to the modular industry so new roles can be determined into the public housing promotion. The most important one probably could be to consider housing like a service in place of a building.

Modular buildings that can be assembled, dismantled and reassembled offer some other important advantages. Lightweight (150-200kg/m^2) make possible to build on low resistance grounds that usually can not resist a conventional building on (2000-2500 kg/m^2) or, in addition, make possible vertical extensions on existing buildings.

Construction-deconstruction condition permits to use ground temporararily because it does not modify the original soil characteristics (there are several locations like that in any Spanish middle or big size cities). Short construction process time (45 days approximately for the whole building) helps to accurately respond to the dynamic location of housing need.

Finally, building evolution (either parts or module units are replaced for newest ones along the building lifespan) can improve the global system performance.

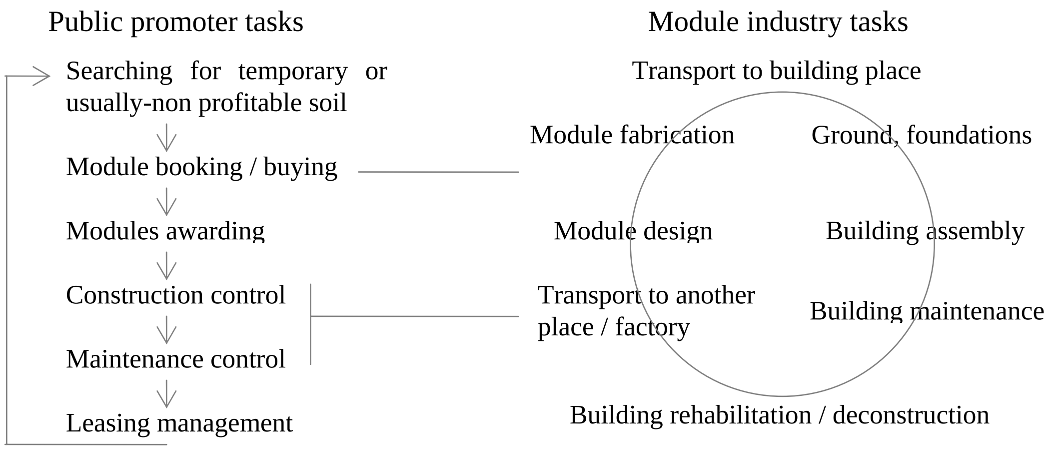

Figure 4. Promoters / industry tasks and the building closed life cycle proposed.

7 CONCLUSIONS

Only 'strong' sustainability will lead to global environmental improvement, as it can revert the process of environmental damage, while 'weak' sustainability merely focuses on parts of the overall problem.

There are two key areas to consider in the search for alternative ways of constructing sustainable architecture: closing the cycle of materials, and using renewable energy sources.

The industrial and commercial characteristics of the light 3D modular systems available in Europe provide an ideal opportunity to formulate an experimental proposal to close the cycle of materials.

The most important material to be used in this area of investigation and development would be steel, due to the mass nature of its use and the fact that it is easy to dematerialise, transport, reuse and recycle.

The technological development that allows for higher levels of sustainability in these construction systems could be used in other systems, using steel and reversible joints.

REFERENCES

Act of the competition jury. Ordenación del Campus y Anteproyecto del Centro de Investigación, Transferencia de Tecnología y Vivero de Empresas, Escuela de Arquitectura del Vallès.

Algeco Modular Construction Spain. Information extracted from its 6000 series modular building technical catalogue.

Anderson, R. 1999. *Mid Course Correction, Toward a Sustainable Enterprise*, The Peregrinzilla Press (eds).126. Atlanta, USA.

ATEG, Technical Association of Galvanization of Spain. Technical dossier for builders www.ateg.es

Ayres, R.U. and Ayres, L.W. 1996. *Industrial Ecology, Towards Closing the Materials Cycl*e, Edward Elgar (eds). 278-282. Cheltenham, UK, and Brookfield, USA.

Ayres, R.U. and Ayres, L.W. 1998. *Accounting for Resources, Towards Closing the Materials Cycle*. Edward Elgar (eds). 2-3 Cheltenham, UK, and Northampton, USA.

British Steel Construction Centre (1), *Environmental designs in steel*, on-line document available at www.britishsteel.com

British Steel Construction Centre (2), *Environmental designs in steel. Guide to thermal capacity in buildings*, on-line available document at www.britishsteel.com

Cuchí, A. 2005. *Arquitectura i Sostenibilitat*. Edicions UPC and Cities (eds). 15-16. Technical University of Catalonia, Barcelona, Spain

De Bobes, A. Tribó, A. 1998. Balanç (energy simulation software developed at the Vallès School of Architecture of the Technical Catalonian University). Sant Cugat, Spain

IISI, International Iron and Steel Institute 2002-2005 world annual reports www.worldsteel.com

Naredo, J.M. and Valero, A. (dir.). 1999. *Desarrollo económico y deterioro ecológico*. Fundación Argentaria (eds). 64-68. Madrid, Spain.

Sustainable Bridge Construction Through Innovative Advances

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ABSTRACT: Sustainability is now recognised as a key issue which much be addressed in the design, construction and life long maintenance of civil engineering structures. In this lecture, generic aspects of sustainability will be briefly discussed, but the main focus will be on its application to bridges. Motorway bridges built in the 1960's/70's had design lives of 120 years; however many were showing signs of deterioration after only 20-40 years. This led to much debate on the issue of initial versus full life cycle costing which is still ongoing today.

In order to address the highly complex issue of the sustainability of bridges the following specific areas which impinge on this important subject will be considered:

1. The impact on sustainability of different forms of bridge construction and maintenance/repair/replacement strategies.
2. The utilisation of innovative *in-situ* testing equipment for assessing the long term durability of concrete.
3. The development of innovative structural designs for bridges which inherently have greatly extended lives at minimal, if any, additional cost.

1. INTRODUCTION

The built environment has to co-exist with the natural environment with which it is inseparably linked. Energy, materials, water and land are all consumed in the construction and operation of buildings and infrastructure to such an extent that sustainable development can be said to depend on the built environment. The world's cities have a major impact on emissions of 'green house gases' and global warming: they take up around 2% of the earth's surface but account for nearly 80% of the carbon emissions from human activities. The urban environment influences our living conditions, social well-being and health. Thus the performance characteristics and quality of our infrastructure are of fundamental importance to urban sustainability and the well-being of our environment. The significance of this should not be underestimated especially if it is borne in mind that our infrastructure accounts for at least 50% of our national wealth.

The burden placed by construction on our natural resources can be estimated from the embodied energy i.e. the total primary energy that has to be extracted from the earth to produce a specific product – usually measured per m^2 of plan area. In addition the operational energy used during their lifetime has to be taken into account. The relative proportion depends on the form of construction. In general, a bridge has high embodied energy and low operational requirements whereas a hospital with its demanding service conditions has a high proportion of operational energy. However for bridges the relative proportions for these energies depends on the extent of maintenance/repair during their lifetime. If minimal maintenance/repairs are required the operational energy may be only marginal however if extensive repairs are necessary and considerable disruption/congestion results the energy consumed can increase dramatically. Thus the challenge for designers is to achieve the minimum total energy used over the 120 year design life and to persuade the client that a sustainable approach is preferable to a minimum initial cost design.

In order to contribute to a better understanding of the highly complex issue of the sustainability of bridges a number of specific aspects which impinge on this important topic will be discussed:

1. The relative merits of different forms of construction from the sustainability viewpoint.
2. The utilisation of innovative in-situ testing equipment which will allow the durability of concrete bridges to be assessed.
3. Technological innovations which could lead to much more durable and sustainable forms of construction for concrete bridges based on:

   (a). The enhanced strength of deck slabs arising from arching action
   (b). A novel flexible concrete arch system

In the latter two instances the approach adopted in research at Queen's University Belfast, carried out with the industry, will be placed in context.

2. SUSTAINABILITY ISSUES AFFECTING BRIDGES

2.1 *The Environmental Impact of New Bridges*

The embodied energy from the use of construction materials is a source of concern to engineers when planning, designing and constructing a bridge. However relatively little advice or guidance is given in the literature as to the relative merits of different forms of construction. In this context a recent paper by Collings [1] presents the results of a comparative study, derived from an actual project. A bridge in the UK over a river of width 120m with 66m of approach spans on each side was considered. The total deck area was over 4000m^2 and this bridge allowed consideration of the shorter spans on the approaches as well as the main river span. Three basic forms of construction were considered for the river span; a profiled girder; a tied arch; and a cable stayed bridge. Constant depth girders were use for all the approach spans. Temporary works were included as was an estimate of the likely repair, maintenance during the life time of the three basic forms of construction; steel; concrete; and composite construction.

Useful comparative tables and graphs are included in the paper by Collings [1] however the results summarising the impact of the span and the form of construction on the embodied energy are only included in this paper. The estimates of the embodied energy during construction (per m^2 for bridge deck) are tabulated in Table 1. Values vary from approximately 16 to 75 GJ/m^2 of deck with the short span concrete structural form giving the lowest values and the all steel or composite, longer span structure the highest. The embodied energy is also presented graphically in Fig. 1, where it can be clearly seen that longer spans consume greater embodied energy/ m^2 (not unexpected as the cost/m^2 also follows these trends). Figure 1 also implies that a well engineered longer span bridge using local materials, recycled steel and sustainable cement can be almost as environmentally friendly as a shorter span structure where sustainability issues are not considered. Table 1 and Fig. 1 also indicate that at the spans under consideration the more architectural solutions (arches, cable stayed) have a higher environmental burden for all materials (as well as a cost premium). Further comparative studies of this nature, by experienced designers, need to be encouraged so that the most appropriate forms of construction, from the sustainability viewpoint, are selected.

Table 1 Embodied energy during construction (GJ/m^2) for various structural forms and materials (from Collings [1])

Energy	Type	Steel	Concrete	Composite
Minimum	viaduct	17.8	15.7/16.6	16.6
	girder	30.9	23.6	29.1
	arch	49.8	34.3	48.8
	cable-stay	40.3	21.1/22.1	37.7
Minimum	viaduct	17.8	15.7/16.6	16.6
	girder	30.9	23.6	29.1
	arch	49.8	34.3	48.8
	cable-stay	40.3	21.1/22.1	37.7
Average	viaduct	23.5	21.1/22.1	22.1
	girder	39.3	30.6	37.0
	arch	61.9	49.1	60.8
	cable-stay	50.6	43.9	47.7

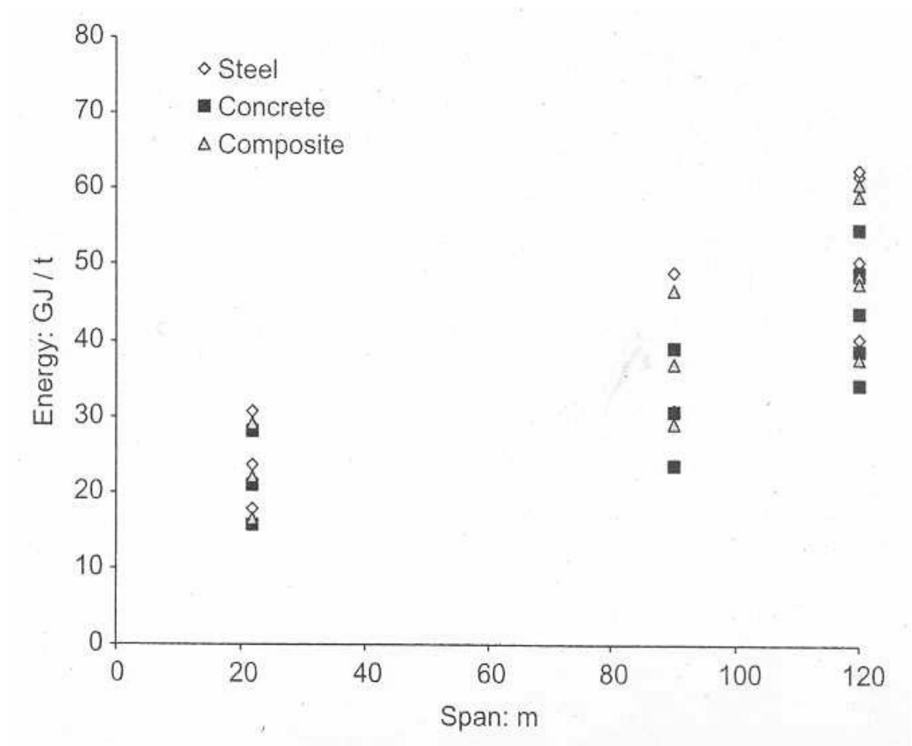

Fig. 1 Variations in embodied energy with span and material type (from Collings [1])

2.2 *Repair, Maintenance and Congestion*

All bridges will require some form of intervention during their lifetime and ideally this, as well as all other aspects, should be taken into account in the design process. Even the most basic maintenance will cause congestion but the impact of replacement can be much greater as exemplified by the Tinsley Viaduct.

The Tinsley Viaduct is a twin deck steel/concrete composite beam girder bridge which carries the M1 motorway and the A631 trunk road across the Don valley near Sheffield. The 1km long structure has 20 spans and crosses two railway lines, the River Don and a canal. As a strategic part of the motorway network, the viaduct carries approximately 115,000 vehicles per day. However in the late 1990's it failed to satisfy the requirements for the introduction of 40t lorries and decisions had to be taken on whether to strengthen or replace the structure.

A replacement bridge was estimated to cost £200 m however the associated cost of congestion over the 2-3 years period of construction was considered to be around £1400m. This enormous additional cost, not to mention the associated environmental impact of congestion, was clearly unacceptable and in the end it was decided to carry out a complex strengthening process whilst keeping the viaduct open for traffic except for a short time each night. In the end the Viaduct was repaired for £80m with minimal congestion resulting – a net saving of £1,500m.

From the viewpoint of the impact of congestion this extreme example demonstrates the importance of having bridges which can be repaired whilst effectively remaining in service. In this regard steel is more amenable to strengthening however the availability of carbon fibre composites allows comparable action to be taken for concrete bridges. It should also be noted that he cost/environmental impact of congestion is an ever increasing problem as many urban bridges built in the 1960's are now in need of remedial action. This should be considered, even if only approximately, in the total life cycle design of future bridges. Whilst this may increase the design cost the long term savings could be enormous.

The relative importance of congestion also requires designers to think carefully about the selection of durable materials and the most appropriate form of construction. As a consequence in the future it will be even more important to build bridges which require minimal maintenance and ensure that premature replacement is avoided.

2.3 *Total Life Cycle "Cost" of Bridges*

Whilst the initial "costs" are useful it is the "cost"/"energy use" over their full life that is more significant. In this context the importance of adopting Integral Bridges [2] for relatively short spans is highlighted. Basically by designing a bridge without movement joints and which is integral from one abutment to the other the maximum resistance to chloride penetration is obtained. As a further step the timely and appropriate application of protective coatings which can be applied whilst it is in service, can delay the need for bridge repair. Thus, by using these methods and some of the innovative approaches detailed later in this paper the life of specific types of bridges can be greatly enhanced and the total life cycle "cost"/"energy use" reduced.

3. DEVELOPMENT OF NOVEL *IN-SITU* TEST METHODS

3.1 *Background*

The single most important parameter that leads to premature deterioration is the ingress of moisture into the concrete [3,4]. Thus, the permeability of concrete to the macro-environment during its service life can be used as a measure of its durability.

In the development of a holistic model for concrete deterioration, Mehta [4] has considered the influence of environmental factors on the various deterioration mechanisms involved. In essence, the permeability influences the primary method of transport of moisture and aggressive ions into the concrete and subsequent increases in the permeation properties are responsible for the increased rate of damage. Thereafter, crack growth (which depends on the fracture strength) accelerates the penetration of aggressive substances into the concrete and the spiral of deterioration continues downwards. The interdependence of all these factors and the importance of permeability/transport properties and strength are clearly illustrated in the holistic model in reference [3].

3.2 *Measurement of Durability Related Properties*

Recognising the importance of these parameters researchers at Queens University Belfast have responded by developing the following three *in-situ* test methods and the associated novel test equipment:

1. The "pull-off" test [5] for measuring TENSILE strength of concrete using the 'LIMPET';
2. Permeation testing [6] utilising the 'AUTOCLAM'; and
3. Assessing the diffusion characteristics of concrete using the 'PERMIT' [7].

All the three *in-situ* tests have been used on site to assess the corrosion induced damage to the Dickson bridge in Montreal [8]. The tests indicated that strength did not correlate well with the levels of deterioration but permeability and diffusivity provided much useful information.

3.3 *Conclusions on in-situ Test Methods*

In the assessment of durability, the following potential uses for strength, permeability and diffusion testing have been identified:

1. *Estimating the life of new structures:* Here the equipment has been used to develop a "mix design for durability" [9] and important trends have been identified (Fig. 2) which could be extremely relevant to new construction.
2. *Assessing the remaining life of existing structures:* The good correlation between permeability indices and durability characteristics can allow remedial action to be taken before irreparable damage has occurred.

Thus, it is essential for practising engineers to work closely with those involved in relevant research. In this context the 'LIMPET', the 'AUTOCLAM' and the 'PERMIT ION MIGRATION TEST' (Fig. 3) could be invaluable tools for generating useful data.

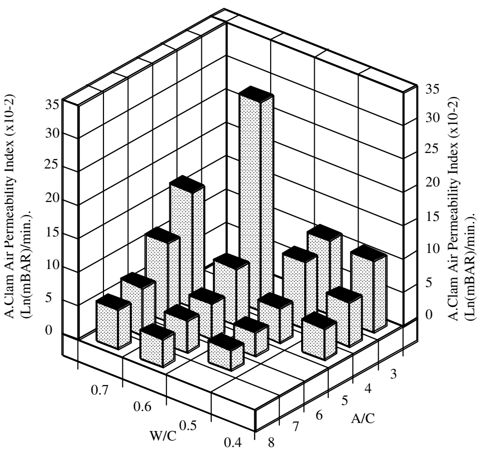

Fig. 2 Influence of mix proportion on Autoclam air permeability index

Fig. 3 Permit, Limpet and Autoclam (from left to right)

4. TECHNOLOGICAL INNOVATIONS FOR ENHANCED SUSTAINABILITY

4.1 *Background*

Bridges with spans of up to 30m constitute the vast majority of road infrastructure bridges in service across the world. Within this category of bridges concrete deck slabs are widely used whether in combination with pre-cast pre-stressed concrete beams or steel girders. In addition, Arch bridges have been widely used in the past for shorter spans and even though their durability is unquestioned their labour intensive methods of construction have rendered these unpopular in recent decades. Technological advances to overcome some of these problems will now be briefly described.

4.2 *Design of bridge deck slabs based on arching action*

By taking the structural advantages of arching action into account in the design process [10] and [11] the following benefits can be achieved:

1. Reduction in reinforcement (from 1.7% to 0.5% or less);
2. Same slab depth for greater spacing of beams;
3. Lower overall cost of bridge superstructure as one larger beam at 2m centres is less expensive than two smaller beams at 1m centres.

Thus, substantial reductions in costs can be achieved whilst at the same time retaining comparable strength and durability (Fig. 4). Research has shown that significant enhancement to durability/sustainability can be achieved by utilising:

1. Concrete with fibres to reduce cracking or taking advantage of the fact that for a given degree of restraint the strength of slabs developing arching action significantly increases with concrete strength.
2. Conventional steel reinforcement located in a single layer at the centre of the slab (greatly increased cover).
3. Glass/carbon fibre reinforced plastic reinforcing bars.

These approaches have performed well in laboratory and field tests as anticipated, and it is clear that by using high strength concrete (with or without fibres) in conjunction with corrosion free reinforcement, bridge decks could be produced which should be virtually maintenance free (Fig. 4).

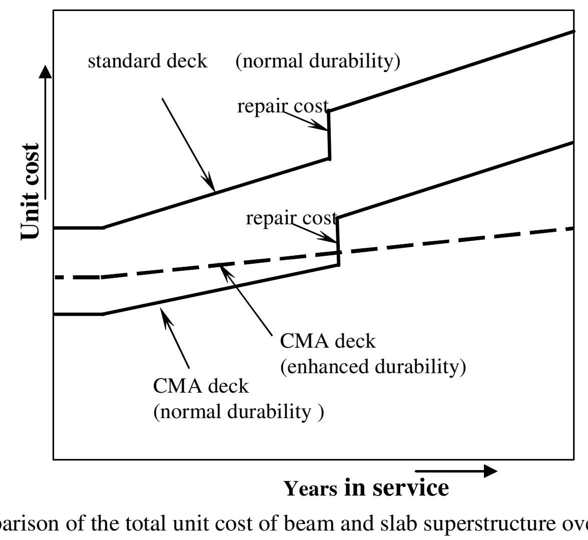

Fig. 4 Comparison of the total unit cost of beam and slab superstructure over their service life

4.3 *Development of a novel flexible concrete arch system*

Brick or stone masonry arch bridges have been utilised for thousands of years and have proven durability. However, it is no longer economically viable to construct a masonry arch in the traditional way due to the cost of accurate centring and the preparation of the masonry blocks. In order to provide a viable alternative Queens University Belfast, in collaboration with Macrete Ireland Ltd, have developed a flexible concrete arch system made of un-reinforced pre-cast concrete voussoirs. The arch system is constructed and transported to site as a flat pack arch. A polymer grid reinforcement is used to carry the self weight during lifting to form a masonry arch. The preferred method of construction of the arch unit is as follows:

> *The voussoirs can be pre-cast individually, laid contiguously in a horizontal line with a layer of polymer grid reinforcement placed on top. An in-situ layer concrete, is placed on top and allowed to harden to interconnect the voussoirs.*

The arch unit can be cast in convenient widths to suit the design requirement, site restrictions and available lifting capacity. When lifted, the wedge shaped gaps close, concrete hinges form in the top layer of concrete and the unit is supported by tension in the polymer grid. The arch shaped units are then placed on precast footings and all self-weight is then transferred from tension in the polymer to compression in the "voussoir" elements of the arch.

The novel arch system has been demonstrated [12], to be a viable alternative to long established methods of construction and the following advantages have been identified:

1. As the Arch system is cast horizontally it can conveniently be transported to site in a "flat pack" form.
2. As centring is not required during installation this greatly simplifies the process and enhances the speed of construction.
3. As there is no corrodible reinforcement the long term durability is assured.
4. The system is cost competitive with less aesthetic RC box culverts.

5. CONCLUDING REMARKS

The sustainability of our infrastructure is now accepted as a key issue in many parts of the world and it is essential that the construction industry recognises the important role it has to play and responds positively to the associated challenges. Within our transportation network, crucial for the continued economic growth of out nation's bridges form a critical part. Deficiencies in the durability/strength of bridges which necessitate repairs/replacement can lead to considerable disruption/congestion within the network and have a very negative impact on sustainability. Thus, bridge engineers will have to integrate aspects of sustainability, such as the relative merits of different forms of construction, maintainability and associated congestion, into the total life cycle cost design process.

Innovative research carried out over the past 30 years at Queen's University Belfast has been aimed at increasing the durability of concrete structures and bridges in particular and has led to the following conclusions:

1. The availability of improved in-situ test methods paves the way for greatly enhanced durability by design for new and existing concrete structures.
2. Advances in structural design based on research on arching action in bridge deck slabs can lead to virtually maintenance free systems.
3. The flexible concrete arch system, which can be transported to the site in "flat pack" form and avoids the need for centring, has great potential.

6. ACKNOWLEDGEMENTS

The input of all my research students, colleagues and friends at Queen's University Belfast and elsewhere, is gratefully acknowledged.

REFERENCES

Collings, D., "An environmental comparison of bridge forms" Proc. ICE, Bridge Engineering, Vol 159, Issue BE4, Dec 2006, pp 163-168.

Highways Agency, "Design of Integral Bridges", BA 42/96, London, 1996.

Basheer, P.A.M., Chidiac, S. and Long, A.E., Predictive models for deterioration of concrete structures, Const and Bldg Materials, Vol. 10, no. 1, 1996, 27-36.

Mehta, P.K., Concrete technology at the crossroads - problems and opportunities, Concrete technology - past, present and future. Proc. Malhotra Symp, ACI, SP 144, March 1994, 1-30.

Murray, A.McC. and Long, A.E. A study of the in-situ variability of concrete using the Pull-Off method, Proc. ICE, Part 2, Vol. 83, Dec. 1987, pp 731-746.

Basheer, P.A.M., A brief review of methods for measuring the permeation properties of concrete in-situ, Proc, ICE, Str and Bldg, Tech Note 603, 1993, Vol. 99, pp. 74 - 83.

Basheer, P.A.M., Andrews, R.J., Robinson, D.J. and Long, A.E.'PERMIT' ion migration test for measuring the chloride ion transport of concrete on site". NDT&E International, 38, (2005), pp 219-229.

Fazio, R., Mirza, M.S., McCafferty, E., Andrews, R.J., Basheer, P.A.M. and Long, A.E., In-situ assessment of corrosion-induced damage of the Dickson Bridge Deck, Proceedings of 8dbmc, Vol. 1, Vancouver, June 1999, pp. 269-279.

Henderson, G.D., Development of design procedures for durable, strong and workable concrete mixes, PhD Thesis, Queen's Univ, Belfast, 1998, pp. 396.

Taylor, S.E., Rankin, G.I.B. and Cleland, D.J, Serviceability of bridge deck slabs with arching action, ACI Structural Journal, Vol. 104, No. 1, Feb. 2007, pp.39-48

Highway Agency, BD81/02, Use of compressive membrane action in bridge decks", Design manual for Roads and Bridges, Vol 3, Sect 4, Pt 20, Aug 2002.

Gupta, A., Taylor, S.E., Kirkpatrick, J., Long, A.E. and Hogg, I. A Flexible Concrete Arch System for Durable Bridges, Proc, IABSE Conf, Budapest, 2006, pp 372-3 (11 pages on CD).

Innovative Forms of Construction for Sustainable Bridges

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ABSTRACT: After a brief overview of sustainability issues details are given of recent research at Queen's University Belfast on two innovative forms of construction, both of which have the potential to be highly sustainable. The first is on un-reinforced concrete bridge desk slabs and the second is the development of a flexible concrete arch system for short span bridges with no steel reinforcement.

1. INTRODUCTION

Within most regions in the world the built and natural environments are constantly interacting and they are inseparably linked. Energy, materials, water and land are all consumed in the construction and operation of buildings and infrastructure to such an extent that sustainable development can be said to depend on the built environment. The world's cities have a major impact on emissions of 'green house gases' and global warming: they take up around 2% of the earth's surface but account for nearly 80% of the carbon emissions from human activities. The urban environment influences our living conditions, social well-being and health. Thus, the performance characteristics and quality of our infrastructure are of fundamental importance to urban sustainability and the well-being of our environment. The significance of this should not be underestimated especially if it is borne in mind that our infrastructure accounts for at least 50% of our national wealth.

Sustainability issues in construction are characterised by their complexity, the diversity of those involved and the need for innovative and special solutions. As the largest and most fragmented industry, the construction sector faces huge challenges in the pursuit of sustainability. Sustainable construction is a way for the industry to move forward, taking into account environmental, socio-economic and cultural issues.

Enhanced sustainability can be achieved through an integrated approach, by adopting innovations in technologies and by taking it into account early in the design process. In this context more detailed information is provided in this paper of two technological innovations which could lead to much more durable and sustainable forms of construction. The development of maintenance free bridge deck slabs and a flexible concrete arch system for short span bridges is backed up by laboratory testing at Queen's University Belfast and complementary field testing.

2. ENHANCED SUSTAINABILITY OF CONCRETE BRIDGE DECKS BY DESIGN

2.1 *Background*

Bridges with spans of up to 30m constitute the vast majority of road infrastructure bridges in service across the world – whether it is for overpasses/underpasses for motorways or for minor river crossings. Within this category of bridges concrete deck slabs are widely used whether in combination with pre-cast pre-stressed concrete beams or steel girders. A similar type of deck can also be utilised for many medium span bridges hence the importance of designing a durable deck system cannot be overemphasised.

Over the past 20 years it has been found that many concrete bridges (concrete was selected in the 1960/70's for its inherent durability) have exhibited problems, such as spalling, associated with reinforcement corrosion. Such problems are particularly prevalent in marine environments or where freezing/thawing conditions require the intensive use of salt to prevent the formation of ice. In the latter case the vulnerability of the reinforcement in the deck slab is exceptionally high and in many instances deck slabs have to be repaired/replaced at great cost within 20-30 years. This causes great disruption to traffic and the associated costs of congestion are high.

A further problem for bridge deck slabs is that they have to be assessed structurally to ensure that they can carry the heavier lorries now on our roads. These deck slabs would in many cases be found to be unsatisfactory were it not for an inherent strength which is not taken into account in normal flexural design approaches. In particular it is accepted that the capacity of the slab elements of beam and slab decks is greatly enhanced due to the restraint provided by the beams and diaphragms. This enhancement has been recognised by a number of bridge authorities worldwide by incorporating it into their national design codes. The recognition of arching action is most important as it can mean the difference between a bridge deck passing or failing the assessment requirements.

In this paper the greatly enhanced strength associated with arching action, which is clearly of benefit for increased loadings, when taken into account in the design process can be shown to produce concrete bridge decks which are more durable than current designs.

2.2 *The concept of arching action in slabs*

With the advent of Johansen's [1962] yield line theory in the 1940s designers and researchers felt that at long last they had a prediction method for slabs which would provide realistic strength estimates. However, the tests carried out by Ockleston [1955] on interior panels of the Old Dental Hospital in Johannesburg revealed collapse loads of 3~4 times those predicted by the yield line method. This enhanced capacity was attributed to the development of an internal arching mechanism arising from the restraining effect of the surrounding panels.

Where a beam is restrained against longitudinal expansion, the concept of arching can best be understood by referring to Fig. 1. With the development of tension cracks at mid-span and at the supports the beam tries to expand longitudinally but as it is restrained, corresponding forces are induced which allow it to sustain a substantial load on the basis of the arching thrusts which develop as the deformation increases. Similar actions take place in two-way systems and this phenomenon is generally referred to as "Compressive Membrane Action" (CMA) The extent of the enhancement provided by CMA, over and above the flexural strength, depends on the degree of restraint provided by the surrounding structure. A typical load deflection curve with the notional contributions separately identified is given in Fig. 2.

2.3 *Relevance to bridge deck slabs*

Tests on model bridge deck slabs in the Civil Engineering Department, Queen's University, Kingston, Canada, in the late 1960s revealed considerable reserves of strength against punching failure [Tong & Batchelor, 1971]. The cause of this enhancement was correctly identified as CMA and its particular relevance to transient concentrated wheel loads was recognised. Bridge decks represent one of the first areas to be considered appropriate for the utilisation of these design concepts because the major localised loading is transient in nature and creep is not significant.

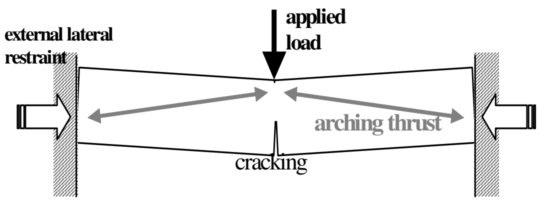

Figure 1: Arching action in a typical bridge deck slab

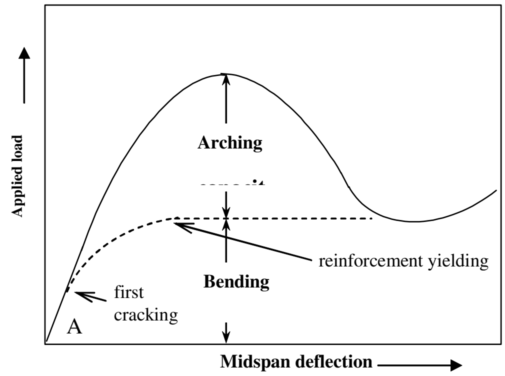

Figure 2: Interaction between flexural and arching action

On the basis of small scale model tests a conservative design method was produced. Thus, in the Canadian design standards [2005] for beam and slab bridges, nominal transverse reinforcement, only 0.3% was required to resist concentrated wheel loadings as opposed to the 1.7% based on flexural design requirements. Similar design concepts are now accepted in various states in the USA and to date no adverse effects have been detected from these reductions in levels of reinforcement.

2.4 *Research on arching action in the UK*

2.4.1 *Validation tests in Northern Ireland*

In the knowledge of the research carried out in Canada on AASHTO girder based beam and slab bridge decks it was decided that parallel tests should be carried out on spaced M-beam (essentially a range of depths of prestressed I-beams with a narrow top flange and a broad bottom flange 1m wide) decks to determine whether similar reductions in transverse reinforcement were possible. This would allow a slightly larger M-beam to be used at a spacing of 1.5m or 2.0m with consequent savings relative to smaller M- beams at 1.0m spacing. In order to establish the strength of the slabs spanning between beams a one-third scale model bridge deck was constructed in the laboratory and tested at Queen's University Belfast, in the late 1970s.

The flexural design of the prototype slab for the two 112.5kN wheel loads indicated that steel reinforcement of the order of 1.7% was required. For test purposes areas of reinforcement equivalent to approximately 1.7%, 1.2%, 0.5% and 0.25% were provided in the model along with three panels equivalent to 2m spacing and two panels equivalent to 1.5m beam spacing providing a total of 20 panels for testing.

2.4.2 *Model test results and prediction method*

The ultimate load capacity of the 20 test panels was determined as the load which caused the loading shoe (simulating the wheel load) to punch through the slab in the characteristic manner. It was found that there was very little variation in the ultimate load capacity of all the panels even though the transverse reinforcement varied from approximately 0.25% to 1.7%. In comparison with design code predictions (Fig. 3) the results of the tests on the one-third scale model with the M-beams spaced at up to 2m apart showed considerable enhancement over the design capacity of the standard slab.

Figure 3 clearly shows that the codes do not give a satisfactory prediction of the punching shear capacity of typical bridge slabs and a more appropriate method which allows for in-plane restraint was therefore developed. This method makes use of an effective steel reinforcement ratio, and full details of the method and its derivation are given in Kirkpatrick et al, 1984. As can be seen from Fig. 3 the proposed method of predicting the punching shear strength of reinforced concrete bridge slabs gives good correlation with the results from the one-third scale model. This method has now been endorsed by the UK Highways Agency.

2.5 *Serviceability of deck slabs*

The ultimate load tests referred to above have indicated that strength is not critical in the design of deck slabs- however; designers also have to satisfy the serviceability limit state requirements. Thus, full-scale tests [Kirkpatrick et al, 1986] were subsequently carried out on a bridge built by the Northern Ireland Roads Service. This bridge incorporated beams at 1.5m and 2m spacing, and the reinforcement varied from 0.25% to 1.7% in the standard 160mm thick deck slab. Initial cracking occurred at loads well in excess of the design service loads and even after cracks had been induced by severe overloading it was found that the slabs still satisfied the serviceability limit state requirements.

2.6 *Review of the advantages arising from CMA*

From a structural viewpoint the following benefits are evident:

1. Reduction in reinforcement (from 1.7% to 0.5% or less);
2. Same slab depth for greater spacing of beams; and
3. Lower overall cost of bridge superstructure as one larger beam at 2m centres is less expensive than two smaller beams at 1m centres.

Thus, substantial reductions in costs can be achieved whilst at the same time retaining comparable strength and durability. However, if the long-term durability of the bridge deck could be increased at a modest increase in cost then the whole life cost could be reduced as can be shown schematically in Fig. 4. Thus, the challenge to designers is to achieve the type of relative performance achieved by the CMA deck (enhanced durability). Significant progress of this front has been achieved in Canada [Mufti et al, 1993] and the UK in recent years.

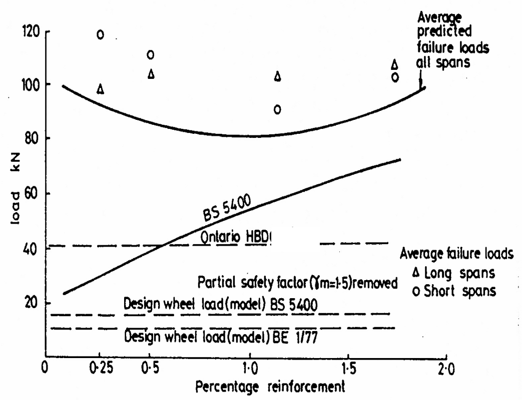

Figure 3: Test results of one-third scale model bridge deck

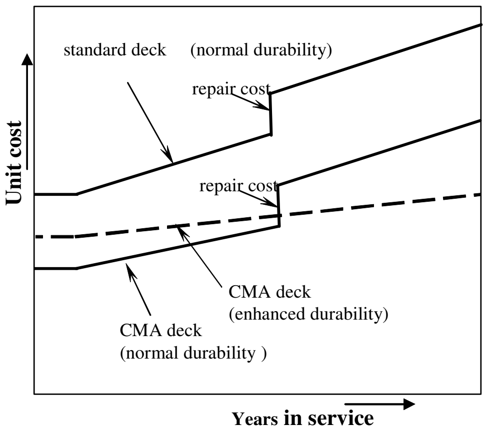

Figure 4: Comparison of the total unit cost of beam and slab superstructure over their service life

2.7 *Improved sustainability by design – developments in the UK*

The system developed in Canada is not applicable to decks with pre-cast prestressed concrete beams which tend to be significantly more popular across the world. Thus, a number of alternative approaches have been the subject of ongoing research both in the laboratory at Queen's University

Belfast and on site in conjunction with the Department of Regional Development- DRD (NI) Roads Service [Taylor et al, 2003]. This work focused on the following subjects:

1) *Concrete* - As well as considering the addition of fibres, advantage is being taken of the fact that for a given degree of restraint the strength of slabs developing CMA is significantly enhanced by increases in concrete strength.

2) *Reinforcement* - Apart from considering the lower percentages of top and bottom reinforcement (0.5% vs. 1.7%) site and laboratory tests have been carried out on:
   (i) Conventional steel reinforcement located in a single layer at the centre of the slab (greatly increased cover).
   (ii) Glass fire reinforced plastic reinforcing bars.

Both approaches have performed well, as anticipated, and it is clear that bridge decks could be produced which should be virtually maintenance free. Because of the lower percentages of reinforcement these need not have a higher initial cost than conventionally decks hence it could be of enormous benefit to bridge owners.

2.8 *Conclusions from CMA research*

A sufficient understanding of the structural benefits of compressive membrane action for bridge deck slabs has now been achieved. This will allow:

(i) The enhanced strength and serviceability of laterally restrained slabs to be taken into account in the assessment of beam and slab bridge decks.
(ii) CMA concepts to be incorporated into relevant national design codes.
(iii) The development of durable deck slabs, which will be virtually maintenance free.

The net effect of all the above is more cost effective bridge decks which exhibit greatly enhanced sustainability relative to existing designs.

3. NOVEL FLEXIBLE CONCRETE ARCH FOR SUSTAINABLE BRIDGES

3.1 *Background to the novel arch system*

Masonry arch bridges are one of the oldest forms of bridge construction and have been in existence for thousands of years. Brick and stone arch bridges have proven to be highly durable as most of them have remained serviceable after hundreds of years. In contrast, many bridges built of modern materials have required extensive repair and strengthening after being in service for a relatively short part of their design life. This section describes the development of a novel flexible concrete arch system that has the potential to be highly sustainable due to the low or zero amount of steel reinforcement. It is no longer economically viable to construct a masonry arch in the traditional method due to the cost of skilled labour required to build the accurate centering and to cut the masonry blocks. Progress on this type of work is usually slow and can be weather dependent. In order to provide a viable alternative Queen's University Belfast, in collaboration with Macrete Ireland Ltd, are developing a flexible concrete arch system made of un-reinforced pre-cast concrete voussoirs. The arch is constructed and transported in the form of a flat pack using a polymer grid reinforcement to carry the self weight during lifting but behaves as a masonry arch once in place.

Basically there are two options for the construction of the arch unit. The voussoirs can be pre-cast individually, laid contiguously horizontally with a layer of polymer grid material placed on top. An *in-situ* layer of concrete, approximately 40mm thick, is placed on top and allowed to harden to interconnect the voussoirs. The same unit can be made in a single casting operation by using a shutter with wedge formers spaced to simulate the tapered voussoirs. Both forms of construction are shown in Figs 5 and 6. The arch unit can be cast in convenient widths to suit the design requirement, site restrictions and available lifting capacity. When lifted, the wedge shaped gaps close, concrete hinges form in the top layer of concrete and the unit is supported by tension in the polymer grid. The arch shaped units are then placed on precast footings and all self-weight is then transferred from tension in the polymer to compression in the arch.

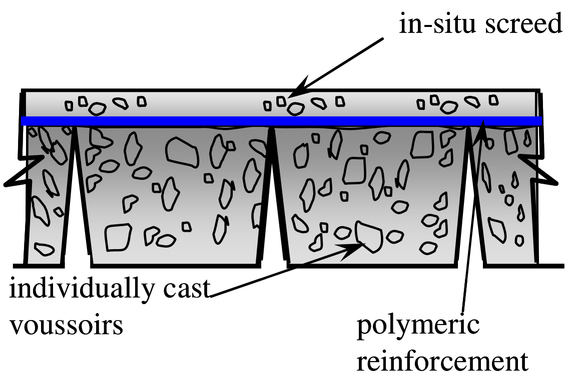

Figure 5: Construction of arch unit using pre-cast individual voussoir concrete blocks

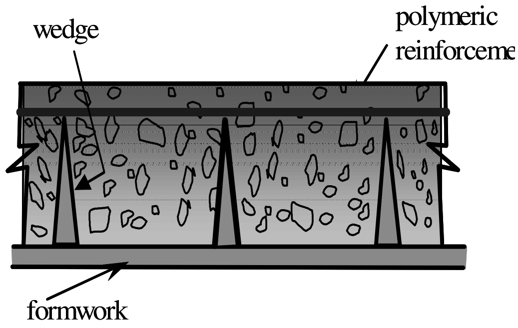

Figure 6: Monolithic construction of the arch unit using a special form of pre-cast wedges

3.2 *Materials*

Paragrid® polymeric reinforcement was utilized in conjunction with the concrete in the voussoirs which had a 28 day compressive strength of around 55MPa.

3.3 *Manufacture of the arch unit*

A prototype arch unit of 5m span, 2m rise and 2.5 m internal radius was constructed and lifted. This arch required twenty-three voussoirs which were 1m wide and 200mm deep with a 40mm slab interconnecting in-situ screed. The arch was lifted at approximately the quarter span points with additional nominal support at the mid-span region. During lifting the arch drags at the each end and the mid span point tends to sag; hence the need for the additional support. When the end cantilevers are fully effective they produce a hogging moment in the mid-span region which assists in the formation of the arch. During this operation a critical case occurs when the arch is fully formed and suspended at the lifting points. A maximum bending moment occurs at the lifting points for the cantilever ends and to simulate this condition a series of short beam elements were tested to establish the capacity and to investigate the rate of creep in the low modulus polymer reinforcement. These were found to give an adequate factor of safety during the lifting procedure. The lifting sequence is shown in Fig. 7.

The arch unit complete with tapered seating is shown in Fig 7c. Subsequently, an anchor block detail was designed for the seating of the arch ring. The anchor block caters for the slope of the last voussoir enabling the arch to from correctly. It also provided some lateral restraint to the arch ring both during construction, prior to completion of the arch system with spandrel walls and backfill, and in the long-term under live loading.

3.4 *Stability test*

3.4.1 Test set-up

To assess the flexibility of this system, a stability test under backfilling operations was conducted and the arch unit was monitored for horizontal deflections, vertical deflections and strain at the voussoirs joints. It was originally intended to use granular backfill. However, after a preliminary cost estimate for this span, it was decided to trial the use of lean mix concrete as a backfill option.

3.4.2 Test procedure and results

The backfilling operation was carried out by placing approximately 250mm deep layers of concrete to each side of the arch to minimise the effects of asymmetric load. The maximum movement at the crown was 0.8mm upwards for the full height of the concrete backfill. Overall the results of the stabilty tests showed very little movement in the arch ring and it was concluded that the arch was stable under the backfill operations.

3.5 *Live load testing of the arch system*

A simulated static wheel load was applied at the mid-span and the third span of the arch ring. The single wheel load (Fig. 8), for the intended category of bridge, is 5.75t. However, for both loading locations the arch system carried over 35t without showing signs of distress (that is, six times the single wheel load).

3.6 *Analysis of the arch unit*

An analysis of the arch unit was conducted using ARCHIE a numerical analysis package which allowed for interaction with the arch backfill. The predicted ultimate capacity was highly conservative when compared with the actual load which was safely carried by the prototype arch system.

Figure 7a: “Flat- Pack”

Figure 7b: Arch Unit during Lifting

Figure 7c: Prototype arch on seating

Figure 8: Test set-up for mid-span loading

3.7 *Conclusions for the novel arch system*

Experience has shown that arch bridges are highly durable structures requiring little maintenance in comparison with other bridge forms. Thus, the objective of the new Highway Agency Standard [2004] is welcomed especially if it encourages a renaissance in arch building using un-reinforced masonry materials. The novel arch system has been demonstrated, Gupta et al. (2006), to be a viable alternative to long established methods of construction and the following advantages have been identified:

(i) As the Arch system is cast horizontally it can conveniently be transported to site in a "flat pack" form.
(ii) As centring is not required during installation this greatly simplifies the process and enhances the speed of construction.
(iii) As there is no corrodible reinforcement the long term durability should be assured.
(iv) Initial estimates would indicate that the system is cost competitive with less aesthetic RC box culverts.

A complete 5m wide arch bridge with a 5m span and 2m rise complete with spandrels, fill and surfacing has been constructed, load tested and has performed exceptionally well. From all view points the system represents a very sustainable alternative for the future.

4. OVERALL CONCLUSIONS

Once designers and contractors have a better indication of what they are looking out for they will be better placed to take sustainability into account right from the inception of a project. In this way and by developing innovative technologies to overcome difficulties progress can be accelerated in this important field. The two examples of innovative approaches to bridges, ie. Un-reinforced deck slabs and the flexible concrete arch, share the following positive sustainability features relative to conventional designs:

- Little or no maintenance throughout their life
- Greatly extended lives

Since these improvements can be achieved at little or no additional cost the problems associated with traffic disruption/congestion when a bridge is being repaired/replaced can be minimised. This recognition of the significance of full life cycle costing, as opposed to the minimum initial cost approach, is very important from the sustainability viewpoint.

5. ACKNOWLEDGEMENTS

The input of all my research students, colleagues and friends at Queen's University Belfast and elsewhere, is gratefully acknowledged.

REFERENCES

ARCHIE-M: Masonry Arch Bridges and Viaduct Assessment Software, Version 2.0.8, OBVIS Ltd. UK.

Canadian Standards Association, Canadian Highway Bridge Design Code (CHBDC), CAN/CSA-S6- (new version for comment 2005 CSA-Tech Comm), Canada..

Gupta, A., Taylor, S.E., Kirkpatrick, J., Long, A.E. and Hogg, I. A Flexible Concrete Arch System for Durable Bridges, Proc IABSE Conference, Budapest, 2006.

Highway Agency: BD 91/04 Departmental Standard, Un-reinforced Masonry Arch Bridges, Design Manual for Roads and Bridges, Volume 1, Section 3, Part 14, Department of Transport, Highway and Traffic, 2004.

Johansen K.W. (1962) Yield line theory Translation by Cement and Concrete Association, London, 1962, 181 pages.

Kirkpatrick J., Rankin G.I.B. and Long A.E. (1984) Strength evaluation of M-beam bridge deck slabs. The Structural Engineer, vol. 62B, no. 2, Sept 1984, pp. 60-67.

Kirkpatrick J., Rankin G.I.B. and Long A.E. (1986) The influence of compressive membrane action on the serviceability of beam and slab bridge decks. The Structural Engineer, vol. 64B, no. 1, March 1986, pp. 6-12.

Mufti A.A., Jaeger L.G., Bahkt B. and WEGNER L.D. (1993) Experimental investigation of fibre reinforced concrete deck slabs without internal steel reinforcement. Canadian Journal of Civil Engineering, vol. 20, 1993.

Ockleston, A.J. (1955) Load tests on a three storey reinforced concrete building in Johannesburg. The Structural Engineer, October 1955, vol. 33, pp. 304-322.

Taylor, S.E., Rankin, G.I.B. and Cleland, D.J, (2003) High performance concrete bridge deck slabs, Proc of ICE, Bridge Engineering, Vol.156, Issue BE2, June 2003 pp.81-90.

Tong P. Y. and Batchelor, B. de V. Compressive membrane enhancement in two way bridge slabs. Cracking, Deflection and the Ultimate Load of Concrete Slab Systems, S.P.-30, ACI, Detroit, 1971, pp. 271-286.

East London Line Sustainability Initiatives

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ABSTRACT: The construction in London of a new railway presents many opportunities for sustainable development. The greatest opportunities arise early in the project development cycle when decisions are made on railway alignment, whether or not to utilize existing facilities in the new project or to construct new facilities tailored to the project requirements, and what requirements to include in the design–build contractor's remit on sustainability issues. This paper describes the development of the East London Line project and the way that sustainability considerations have been incorporated.

1 BACKGROUND

The need for an orbital railway that would run around London outside the existing Circle Line has long been recognized. In the early 1990's the Strategic Rail Authority (SRA) developed a scheme to create an orbital line from two existing railway lines; the East London Line and the North London Line

The present day East London Line began life as the East London Railway. Construction began in 1865, and even then, included a major element of infrastructure recycling, namely the reuse of the existing Thames Tunnel which had been built by Mark Brunel and his son Isambard Kingdom Brunel between 1825 and 1843 for use by horse drawn vehicles to move goods into London from the docks located on the south bank of the Thames. Though the tunnel was completed, lack of funds prevented the construction of the approach ramps and the tunnel was never used for its intended purpose. For 22 years after its completion the tunnel was used mainly as a foot tunnel until in 1865 it was taken over by the East London Railway which constructed the approaches and laid tracks to the north and south of the tunnel to create a railway line from New Cross Gate at the Surrey Docks on the south bank of the Thames to Liverpool Street Station, a major rail terminus on the east side of London. The tunnel section from New Cross Gate to Wapping on the north bank of the Thames and which includes the historic Thames Tunnel was opened to rail traffic in 1869. The section from Wapping to the Liverpool Street Station of the Great Eastern Line opened for service in 1876.

Now, as a key element of the proposed orbital railway, the East London Line - see Figure 1, will be extended from just south of the new Shoreditch High Street Station where it once joined the Great Eastern Line for a distance of 3 km north to Dalston Junction where it will connect to the North London Line, and in a second phase of the project, to the west from Surrey Quays to Clapham Junction to complete the loop and make to an orbital line a reality.

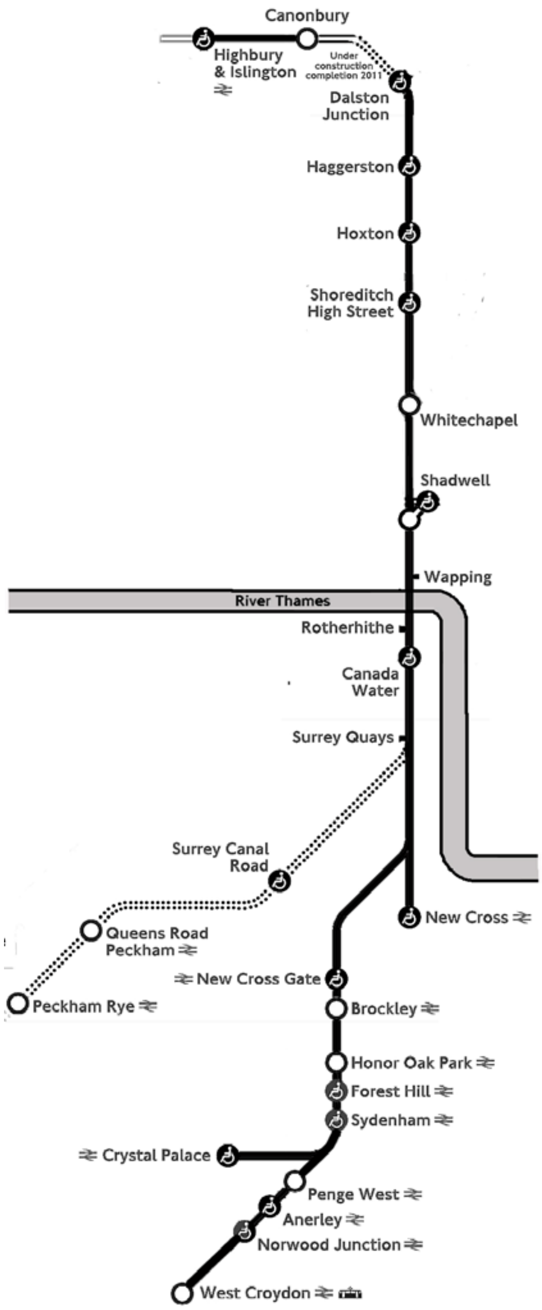

Figure 1 – The East London Line

2 THE EAST LONDON LINE

In London, where the costs, both monetary and social, of acquiring new surface rights-of-way are extremely high, any railway extension in the central urban area will normally be in new tunnels constructed for the purpose e.g. Crossrail or the Channel Tunnel Rail Link (CTRL) or will utilize existing infrastructure such as unused railway rights of way if available. For the East London Line, the disused Kingsland Viaduct, a brick arch viaduct completed in 1876 and which carried the North London Line between Dalston Station and Broad Street Station until 1984 when it was closed in a restructuring of the British Rail, provided just such an opportunity for the northern extension of the East London Line from Shoreditch to Dalston Junction.

For the central section of the project from Whitechapel Station to Surrey Quays there were two choices; utilize the existing East London Line tunnels, including the Thames Tunnel and approaches or, construct new surface or sub-surface routes from scratch. The Thames Tunnel had just been refurbished in 1996-98 with new reinforced concrete lining and trackwork and its dimensions and condition made it suitable for continued use as part of the orbital railway. The approach tunnels on either end of the Thames Tunnel are of cut and cover construction and have been in service for more than 130 years. Their condition too was deemed suitable for continued service in the orbital railway and so given the cost and disruption of a new alignment and the suitability for continued service of the existing tunnels, the decision was taken to use the existing East London Line alignment for the central section, even though this meant that East London Line rail service would be halted during reconstruction. Repairs to the approach tunnel sections will be carried out in 2008/09 when the East London Line is closed for a 30-month period to replace the existing trackwork, signalling, power and communications systems with new trackwork and systems to orbital rail standards. Once the East London Line Line is closed at the end of 2007, the tunnels, and particularly the tunnel inverts will be fully surveyed and the full extent of repairs determined. Innovative repairs, including carbon fibre wrapping of cast iron struts, are planned.

The southern extension from Surrey Quays utilizes a combination of existing East London Line alignment and Network Rail tracks between New Cross Gate and West Croydon / Crystal Palace. The existing tracks will be removed and replaced, and several substandard bridges will be replaced while the line is closed. The remaining works in the southern section consist principally of a stabling yard, a train maintenance facility and an operations building complex, all of which will be constructed on a brown field site at New Cross Gate where disused Network Rail sidings and carriage maintenance facilities once stood.

3 SUSTAINABLE ASPECTS OF THE PROJECT

The concept of sustainable development was defined in the 1987 Bruntland Commission report ‘Our Common Future’ as “…. development that meets the needs of the present without compromising the ability of future generations to meet their own needs…”. The UK government’s strategy for sustainable development (A better quality life: a strategy for sustainability development for the UK (CM4343 1999) describes sustainable construction as balancing four main elements:

- Effective protection of the environment
- Social progress which recognizes the needs of everyone
- Maintenance of high and stable levels of economic growth and employment
- Prudent use of natural resources

At a project level, the UK government has set targets in the following areas:

- Carbon neutrality
- Carbon emissions
- Energy efficiency
- Waste and recycling
- Biodiversity
- Water consumption

The Mayor of London issued the policy document “Sustainable Design and Construction May 2006” as a Supplementary Planning Guidance to the London Plan setting out a series of standards for sustainable design and construction in London. The guidance sets out lists of both “essential standards” and “preferred standards” and both lists of standards provide the basis for sustainability initiatives for the East London Line Project.

Sustainable design of the East London Line falls into two major areas of responsibility:

- At the conceptual design stage, planning decisions made regarding alignment, station locations, budgets, policies and procedures and similar. These key decisions were made directly by TfL and its predecessors and through the Transport and Works Act processes

– At the detailed design stage, decisions are made on material selection, waste management, reuse of materials. These decisions are made by the design-build contractor to meet established project standards

4 SUSTAINABILITY CONSIDERATIONS IN CONCEPTUAL DESIGN

4.1 *Environmental Sustainability*

The orbital railway will provide better rail links between suburbs and for rail travellers whose destinations require them to cross London and will bring metro style transportation to a depressed area of London. This will reduce use of cars and buses to make these trips and divert travellers on to a transportation mode that is more energy efficient and less pollutive. There is also the added benefit that reduced use of cars and buses will reduce congestion on streets and improve traffic flows, again with a commensurate reduction on air pollution

Maintaining existing structures keeps historic links to the communities past. The Kingsland Viaduct, a disused section of the North London Line running south from Dalston Junction to just north of Shoreditch High Street will be rehabilitated and put back into service. The Kingsland Viaduct is an integral part of the Boroughs of Hackney and Tower Hamlets, having been an important transportation corridor at the time that these boroughs developed. Reintroducing trains to the viaduct will be a natural fit with the layout of the boroughs and will make very little impact on the existing borough infrastructure.

Between Shoreditch High Street and Hoxton stations, the East London Line crosses an area containing a number of sites of archaeological interest. Archaeological investigations are being carried out on the project's behalf by the Museum of London

– The site of the Holywell Priory, a medieval site of significant archaeological potential. All areas to be disturbed by construction will be excavated in advance by archaeological teams
– The Bishopsgate Goodsyard is a site that was urbanized in the 17th and 18th centuries, then subsequently redeveloped for railway use following the arrival on one of London's first railways, the Eastern Counties in 1839. Archaeological teams have excavated representative locations before releasing the site for construction.
– The Shoreditch High Street bridge which will span what was originally a Roman road. The bridge abutments will be excavated to locate and preserve any roman artefacts or roman building remains within the footprint prior to construction.

In addition, the archaeological team will assist under a watching brief at other locations where foundations are to be excavated and will also carry out a programme of surveying and photographing structures to be demolished ahead of the demolition

The East London Line runs alongside, and even utilizes a number of historically important structures. These structures are classified by the UK government and must be protected from damage or alteration. At Bishopsgate Goodsyard, the grade II listed Braithwaite Viaduct which formed the initial construction of the goods yard structure was saved from demolition. The Braithwaite is an early example of brick masonry arch viaduct with the added feature of pointed arch construction rather than the more usual circular arch. The East London Line has been designed to run alongside the Braithwaite Viaduct without damaging the structure.

At 196 Shoreditch High Street, a seventeenth century grade II listed building was purchased by TfL and has been strengthened and to allow viaduct construction, which passes within 150 mm of one corner of the building, to proceed without damage to the structure. At the grade II listed Crystal Palace Station, new platforms and turnback tracks are required for East London Line service. The station was constructed in the 1850's to serve the original Crystal Palace after it was moved from Hyde Park to Sydenham and new construction will be designed to avoid impacting the original structure.

The East London project is located largely on land that either still is or has been used for railways. The East London Line's reuse of the existing active and disused railway land turns disused railway viaducts and abandoned railway yards back into productive use and upgrades property that otherwise lies abandoned and contributing to urban blight.

4.2 *Social Sustainability*

The project has been planned to increase the availability of public transport to the communities along the corridor, and provide better links to London's extensive underground and surface rail systems. The project expects to encourage a shift from road to rail travel, reducing road congestion in eastern London and reducing the fuel used per passenger mile.

The project will increase community access to services and facilities throughout the London area and will create employment opportunities for east London residents, both in the short term through construction related jobs and longer term as businesses establish at locations along the alignment.

The East London Line will also provide a major benefit in 2012, by providing improved rail connections to the Olympic sites, reducing reliance on motor vehicles and reducing congestion on crowded east London streets.

4.3 *Economic Sustainability*

The Kingsland Viaduct, being a brick arch structure has provided some 150 rental spaces for use by a variety of small business enterprises. Now the arches will be renovated and waterproofed as a part of the viaduct rehabilitation extending the life of these low cost facilities that these small businesses need. In comparison, modern viaduct structures would not likely be of a construction type that would offer small businesses comparable facilities.

The City of London is expanding eastwards to take advantage of old commercial and industrial sites that are close to the City. The Bishopsgate Goodsyard site is a major undeveloped site and once the East London Line provides the necessary transportation links, will become a prime development site within a short distance of the current City.

At Dalston Station, the East London Line project will construct a podium slab above the Dalston Station that will be suitable for mixed-use development buildings of up to 15 stories. It is anticipated that the combination of a new railway station together with a new mixed-use development will provide the catalyst for further redevelopment in the area.

In addition to the signature redevelopment sites at Dalston Station and at Bishopsgate Goodsyard, the other new stations are expected to stimulate redevelopment and growth along the railway. For example, the Docklands Light Railway which passes through the disused London Docklands area and which connects with the present East London Line has stimulated growth and redevelopment at many of its stations through the old docklands area. A similar stimulus to redevelopment is anticipated with the upgrading of the East London Line.

4.4 *Use of Natural Resources*

Reuse of existing structures avoids the need for new materials and the disposal of existing materials and is a strong positive aspect of the project. Furthermore, the re-use of active or derelict railway alignments fits well within the context of communities that that developed around the railway and therefore lend themselves to renewed rail service

The Kingsland Viaduct is approximately 1,800m in length and the ability to reuse the viaduct for the extension to Dalston Junction avoids the need for this length of new viaduct or tunnel. This translates into a savings of some 38,000 m^3 of reinforced concrete and the elimination of the need to demolish and dispose of approximately 90,000 m^3 of brick masonry. This equates to some 12,800 round trips by trucks no longer required.

The rehabilitation works on the viaduct included the replacement of 11 short span bridges, which were originally of cast iron beam and jack arch construction with modern steel beam and reinforced concrete deck structures, the strengthening of existing brick masonry bridge abutments, and the repair and upgrading of a further 10 riveted steel beam bridges. The rehabilitation works also included the waterproofing of the entire viaduct with a modern waterproofing membrane. Preserving the riveted steel and jack arch bridges helps maintain the architectural integrity of the viaduct and preserve examples of a construction method no longer used.

Water Harvesting. The train maintenance facility at New Cross Gate requires the construction of a maintenance shop building approximately 100m by 38m. The 3,800 m2 footprint provides the opportunity for rainwater harvesting. Rainwater runoff from the roof will be captured and stored in underground tanks for use in the train wash plant and wash down facilities.

Regenerative Braking. The East London Line is purchasing new trains to replace the old East London Line stock. The new train sets, in addition to providing improvements in overall efficiencies from advances in motors and drives over the past 25 years, are equipped with regenerative braking which allows the energy from braking to be recaptured and reused instead of being dissipated as heat as the current train sets do. Regenerative braking is relatively new, and while the East London Line train sets will not be a first in England, they are, nevertheless, an example of how the East London Line is supporting the use of advanced technology to reduce the use of energy.

5 SUSTAINABILITY CONSIDERATIONS DURING DETAILED DESIGN AND CONSTRUCTION

5.1 *Sustainable Design Requirements*

The project requires the contractor to develop a sustainable design plan to identify sustainability issues for consideration during design development. The contractor's plan must provide for showing how initiatives have been incorporated into the design, reasons why it was not possible to fully implement any of the identified initiatives and demonstrate that the detailed design was compliant with the project's sustainability requirements. The project requires the contractor to be certified to BS EN ISO 14001 and also requires the contractor to consider whole life costs in the design. Both are considered to be positive factors in reducing the environmental impact of the project.

To monitor the performance of the design against the sustainability initiatives, an agreed set of Key Performance Indicators (KPI's) have been agreed with the contractor. The KPI's have been selected to meet SMART criteria, i.e. **S**pecific, **M**easurable, **A**ffordable and **T**ime-related. The project has specified that KPI's are to address the following topics.

- Energy – predicted total energy use and carbon emissions for the new stations and operational building complex. The contractor will evaluate the performance of his design against baseline energy and emissions of the notional buildings calculated in accordance with Building Regulations methods.
- Noise and Vibration – compliance with project criteria for airborne noise, ground-borne noise and vibration.
- Materials – Percentage of re-used and recycled content from the top 10 supplied materials in terms of spend and volume. The contractor will be required to meet or exceed project standards for re-use and recycling.
- Bio-Diversity- Substantial areas of new habitat are to be created as part of the landscape works along the route. The area of seeded substrate bed created will be compared to project targets
- Drainage – drainage using sustainable urban drainage systems (SUDS). The contractor will measure the areas of new construction and areas of existing and former railway sites that are drained to a SUDS system.

KPI's have substantial financial incentives attached, making it worthwhile for the contractor to meet or exceed KPI targets.

5.2 *Environmental Sustainability*

Included in the tender documents for the design–build contract is a Code of Construction Practice (CoCP) which is an agreement between the project and local authorities setting out general construction principles and environmental requirements to be followed during project construction. Typical issues addressed in the CoCP include noise and vibration, hours of work, traffic routes, and dust. The CoCP is also a vehicle for the local authorities to address issues of particular concern during construction, such as any special restrictions near schools.

While the CoCP addresses noise resulting from construction activities, the contractor is also responsible for producing a design that will meet project noise and vibration criteria. For example, selection of the railway track form, whether to use steel or concrete to construct the viaducts and what noise mitigation structures to install along the track will all determine how much noise residents alongside the tracks will hear. It is the contractor's responsibility to produce a design for each of these individual elements that in aggregate, will result in an operating railway that meets the project noise and vibration criteria

The project has established overall landscaping goals and guidelines, but leaves it to the design-build contractor to integrate the landscaping into the civil and structures designs. The contractor is to produce an integrated design that balances the civil elements with the landscaping needs, rather than having landscaping as an afterthought. The project also specifies a preference for native flora, and a further preference for species that are nectar rich and berry bearing.

5.3 *Social Sustainability*

The East London Line passes through two of the most economically depressed Boroughs in London. Arguably, the most important aspect of social sustainability is the potential impact of the project on local youth. The project has included requirements for the contractor to hire local workers, buy materials from local businesses, and implement an outreach programme to local schools and colleges to give local youth the opportunity to learn a construction trade and gain meaningful on–the-job experience that will last a lifetime. When the anticipated redevelopment of these areas occurs once the East London Line is reopened, the training and work experience that the local residents have received during the construction phase will allow them to participate as well in the development projects that follow.

The project has also relocated a community resource in the borough of Tower Hamlets, the Spitalfields City Farm which is located on a covered way above the existing East London Line. Spitalfields City Farm provides the local community access to open space, garden plots, and has pens for farm animals. Though not a requirement of the TWA, the project has worked closely with the farm management and the Borough to relocate the farm so that this resource will not be lost to the community.

5.4 *Economic Sustainability*

While under construction, the East London Line will provide job opportunities for the residents, and opportunities for local businesses. The contractor has to comply with project requirements to engage with the local communities and apprise them of work and commercial opportunities. A successful outreach programme will not only provide the local communities with opportunities in the short term while the East London Line is being constructed, but more importantly, will equip the communities to continue to participate in the redevelopment projects to come.

5.5 *Use of Natural Resources*

By its nature, the East London Line offers substantial opportunities for recycling. For example 27,000 tonnes of crushed brick arisings from demolition of masonry arches at the Bishopsgate Goodsyard are being used on site for backfilling, avoiding the need to transport the brick arisings to a landfill and for importing suitable fill materials.

A similar quantity of ballast resulting from the removal of the existing East London Line ballasted tracks may be recycled either on the East London Line as fill materials or cleaned and rescreened for use as ballast on other railway locations. Alternatively, the ballast can be used as fill material.

On the Kingsland Viaduct, the existing subgrade material was partially removed for the installation of waterproofing membranes. The subgrade material was then screened and reused to provide the engineered materials required for the protective layers above and below the membrane as well as for the structural subgrade below the new railway tracks

Some 12,000 m of the existing East London Line trackwork will be removed and replaced. The contractor will be responsible for identifying ways to recycle the steel rails, the timber and concrete sleepers and the ballast. The contractor's performance will be measured as part of the KPI process.

In order to minimize waste, the contractor is required to pursue a strategy of ensuring that any surplus materials will be managed, so far as is reasonably practicable, to maximize the environmental benefits from the surplus materials and where they need to be disposed of, to ensure that they are handled in accordance with legislation and best practice.

6 CONCLUSIONS

The East London Line project has taken an aggressive stance in promoting sustainable construction, both in the project development stage and throughout design and construction. The decisions taken during design development stage have been made with sustainability in mind, and the inclusion of sustainability requirements in the design- build contract will ensure that sustainability continues to be in the forefront. Projects like the East London Line demonstrate the role that transportation projects play in sustainability, particularly in their ability to promote regeneration and encourage modal shift from road to rail. In the case of the East London Line, the sustainability is further enhanced by the ability of the project to reutilize abandoned or underutilized infrastructure.

The first cooperative building of sustainable housing in Portugal

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ABSTRACT: The First Cooperative Building of Sustainable Housing in Portugal

1 MEETING THE PORTUGUESE SUSTAINABLE PROJECT OF PONTE DA PEDRA

The Project of Ponte da Pedra came out of an Ideas Competition, which is, by the beginning, a good indicator of the high quality of the housing architecture of Ponte da Pedra. Between the development of the urban and residential idea (September 1998) and the conclusion of the construction (February 2007), 9 years have passed, in a cruise speed.

The construction of the building replaced an old tannery, improving the quality of the local site, since, far beyond the housing promotion, we have promoted an environmental and urban regeneration.

The first phase of the Building is composed by 6 Blocks that gather 150 dwellings, an educational and cultural equipment placed in the north of the new street and a sports area in the middle of the housing area.

Th second phase of the building is composed by two blocks (Block 7 and Block 8 – 101 dwellings) and also has a child equipment, public park and water mirror, with gardens and sidewalks all over the building.

The housing ensemble creates neighborhood spaces, leisure areas, also having an improving and appropriated connection with the surrounding area.

From the President of the Cooperative Union, the architect responsible for the project and the Technical Director until the building company, all these agents were very important keys in the development and success of this pilot initiative in Portugal. We also count on the academic support of Prof. Eduardo Maldonado, Faculty of Engineering of the Oporto’s University, and Prof. Manuela Almeida, Minho’s University.

This second phase represents the Portuguese participation in the SHE Project (Sustainable Housing in Europe) as a consequence of the application of this Second Phase to this Project.

The SHE Project has the support of several institutions that come from 4 European countries – Italy, Denmark, France and Portugal, and aims to demonstrate the real feasibility of Sustainable Housing as far as the economic, the environmental, the social and the cultural issues are concerned, using, for that purpose, European cooperative constructions as dissemination pilot projects of a new method of construction that we want to adopt in future constructions. The Project was recently awarded, on the 2nd February 2007, with an Energy Efficiency Prize 2007, in the Category Public – private partnership, by the Directorate-General Energy and Transport of the European Commission, on the scope of the Sustainable Energy Europe Campaign 2005-2008, which says a lot about the importance and the pioneering initiative of this Project to which we belong.

The second phase of our pilot project started in February 2005 and was achieved in February 2007 and is now in operation, since it is already inhabited.

It is a building of 9.216.160, 00 €, co financed by the SHE Project with the institutional support of FENACHE (National Federation of Cooperative Housing, F.C.R.L.) and FEUP (Faculty of Engineering of the Oporto's University).

This second phase keeps the same building features of the 1st Phase, having an external technical follow-up of the building's construction with a ten year insurance policy (that protects dwellings against structure defaults that might appear during a ten year period), hygiene, safety and health external control in the building site, supervision of building works directed by an Engineer from NORBICETA and coordinated by the Tecnhical Manager of the Cooperative. The management model of the dwelling also respects the NP EN ISO 9001:2000 rules, since the Quality Management System implemented in a single Cooperative was also adopted by the other Cooperatives that belong to the Union.

Apart from these indicators, we have a group of building features in the second phase of the building that really distinguishes it from the conventional construction and that gives it the title of *The First Sustainable Building of Cooperative Construction in Portugal.* This promotion is, nevertheless, a cooperative construction under controlled costs, approved and subsidized by the National Institute of Housing.

2 HOUSING SUSTAINABLE FEATURES

We, obviously, make reference to the housing sustainable features, according to the SHE Project that are organized according to the following horizontal activities:

2.1 *The participation process*

The involvement of several stakeholders in the different steps of building's development, especially local authorities, the Cooperative Union, the building company, the design team, technical staff, inhabitants and future users, achieving the target of social cohesion, through the effective participation of these stakeholders in an Integrated Strategy of Sustainable Development:

- Weekly meetings with Project Designers, representatives from the building company and the Housing Cooperative;
- Opened sessions on the Building's presentation and Project discussion;
- Documents to support the main dissemination moments of the building's promotion;
- User Manual to allow a correct use and maintenance of sustainable dwellings;
- Edition of a quarterly magazine that updates the development of the activity of the Cooperative promoter;
- A website that uploads, every three month, the information concerned.

2.2 *Building's integration in the local site*

Building's integration in the local site in a positive way, respecting land management constrains and local ecosystems and promoting, on the other hand, biodiversity. Ponte da Pedra building has significant information on this subject. The building has replaced a very poor area by an important building and regeneration initiative, that respects solar exposure, profits the local water vein and, since it is very close to a public transport network, it potentially reduces the use of cars and the mobility impact of inhabitants.

2.3 *The choice of materials*

The use of materials that respect and protect the environment, whether for its reduced impact, local provenance and low need for maintenance, whether for their durability, recycled, recyclable or reusing potential. Our building has preferably chosen locally or regionally produced materials with a very low need for maintenance, considering the underdeveloped situation of our country as far as the use of the Ecolabel or life cycle cost analysis is concerned.

2.4 *Water Cycle Management*

The respect for the existing water cycle and the reduction of clean water consumption, through the use of technologies and equipments that allow water saving and through the reduction of the loss of the infiltration rate:

- Showers with thermostatic valves for temperature control;
- Garden watering with humidity sensor;
- Use of double flush in toilets (6 liters or 3 liters);
- Building of an underground water tank to store rain water and the water that comes from the local vein to be used in the toilets and in the garden watering of the whole Ponte da Pedra ensemble.

2.5 *Waste Management*

An appropriated waste management during the construction and the use, reducing, separating and reusing waste:

- Containers to separate waste during the construction, with the support of the urban services;
- Creation of outside eco points for waste separation during building's use;
- Placing differentiated waste bins inside dwellings.

2.6 *Energy Management*

The construction of a highly efficient energy building, considering maximal use of passive solar potential (building's orientation), minimum consumption levels, the use of renewable energy technologies, the installation of highly efficient equipments, materials and equipments selection with a low embodied energy and the information of the future users about the best practices of energy needs (through the user manual).

Let's have a look at the building's solutions that assure the reduction of heating and cooling and the energy need for sanitary hot water aiming to certify the building in terms of energy efficiency:

- Study of the building's solar orientation, profiting passive solar potential and reducing the need for environmental heating inside dwellings;
- Development of thermal insulation systems of the surrounding that totally excludes thermal bridges and that considers a K=0.35 for surrounding elements that are in contact with the exterior;
- High thermal insulation, according to the new Regulation of the features of Building's Thermal Behavior;
- Use of solar panels on the building's roof, profiting a renewable energy source for sanitary hot water heating, deeply reducing the consumption levels of natural gas and electricity;
- Use of low consumption bulbs and electronic systems in every common areas, turned on by solar cells placed outside;
- Use of movement detectors in main rooms, staircases and corridors;
- Adoption of crossed ventilation inside dwellings, being preferably natural as an important indicator of inner comfort aiming to reduce the need for cooling;
- Construction of a class A energy efficient building.

2.7 *Daylighting*

Management of daylighting, respecting legal requirements as far as the level of natural and artificial lighting is concerned, assuring an efficient coordination between both and a high percentage of spaces with natural lighting:

- Building respects legal requirements as far as luminance levels are concerned inside dwellings;
- In the case of artificial lighting, we use equipments that allow energy saving (as it is explained in the chapter of energy efficiency)

2.8 *Acoustic comfort*

Acoustic Comfort controlling noise outside and inside the building:

- Planting a tree barrier in the building's surrounding that "works" as a noise barrier;
- Use of horizontal and vertical acoustic insulation, between dwellings and between those and common areas.

2.9 *Energy, environmental, social and economic building's monitoring*

Energy, environmental, social and economic building's monitoring that will take place for a year, between March 2007 and February 2008, when the building is already inhabited. This monitoring will allow the measurement of the sustainable building's performance. For instance, as far as gas, electricity and water saving is concerned, we expect to reach an extremely good performance in a way that from the 4^{th} year forwards, all savings will be net, as a result of the additional investment that each family had to do when buying their sustainable dwellings (the price for sail was 5% above the traditional cooperative building). During this period, we would also be able to understand the social benefit of a Sustainable Construction, which is a key element that can motivate state financial supports, whether local or regional, whether national, that will stimulate sustainable construction practices.

3 POSITIVE OUTPUTS OF A SUSTAINABLE EXPERIENCE

It is extremely important to underline that this project completely changed the pattern of cooperative housing promotion in Portugal. From now on we have committed ourselves to always promote sustainable buildings, respecting as much as possible the principles learned with the SHE experience, but always taking into account the specificities of each project. In Portugal, we have completely adopted the purpose of the SHE Project – to make sustainable construction a common practice in Housing Cooperatives.

Apart from this output, we may also underline that the National Federation of Cooperative Housing, also a SHE Partner, has adopted a Declaration for the Quality in Cooperative Housing. This document is a strategic goal that intends to qualify management and operational methods among the Portuguese Cooperatives and it clearly assumes sustainable construction as a Compromise that every Cooperative must sign.

Government authorities have also recognized the importance of this cooperative step: local municipality has assumed, in a public seminar that sustainable projects will have a priority treatment with tax exemptions and that social housing promoted by the local council must also respect the same principles. On the other hand, there was an important change in the national legislation that declares that government will support the promotion of sustainable dwellings, in new or retrofitted buildings, since they will have outright grants.

These extremely important outputs give us the strength to carry on and do as better as we can, improving techniques, innovating methods and stimulating behaviors.

Directing sustainable investments in commercial real estate

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ABSTRACT: This paper focuses on the facility costs, energy use and water consumption of commercial real estate. A framework consisting of four components is established in which the performances on these three aspects are analysed. By using the first, second and third part of the framework suggestions for reducing the energy and water consumption can be given. The building related facility costs form the fourth component, which make it possible to give a more profound direction to cost-effective sustainable measures. The framework was applied to three Dutch office buildings from comparable age with a floor area up to 37.890 m^2. The combination of qualitative, quantitative and financial analyses can be an useful instrument for facility managers to manage and reduce facility costs effectively.

1 INTRODUCTION

Buildings are accountable for a large part of the yearly energy consumption of many nations. Within the European Union the energy consumption of the residential and tertiary sector is more than forty percent of the final energy consumption. The energy consumption of this sector is even bound to increase (EC 2002). According to Campbell the annual energy consumption of offices in Northern Europe varied between 270 and 350 kWh/m^2 (1988). In European office buildings the annual energy consumption ranged thirteen years later from 100 to 1,000 kWh/m^2 (McNicholl & Lewis 2001).

Governmental and commercial organisations feel the need however to lower the energy consumption of their real estate, because of increasing energy prices and the aim to reduce greenhouse gas emissions. By gathering information on commercial real estate objects and their consumption patterns, a strategy to effectively lower energy use and water consumption can be developed.

The inventory of buildings can take place by using the methodology of Santamouris et al. (1994) that distinguishes five kinds of information to analyse the energy consumption. Although these kinds of information are necessary to determine the potential for energy conservation and to investigate the possible limitations of energy saving technologies, it does not offer the necessary insights in the financial aspects of energy saving investments or investments that improve the sustainability, to convince the facility management of their necessity. Therefore in this research information on facility costs was incorporated in a new assessment framework. This framework was applied to three Dutch commercial real estate objects.

2 METHODOLOGY

In the initiation phase of this research project the curiosity for what is known by the user about the building's sustainability, maintenance costs, energy use, and water consumption offered a new perception on analyzing commercial real estate objects historically. Interviews were taken with the wardens of the objects to get information on their view on its sustainability and their experiences with making the object more sustainable.

By taking interviews among the wardens it was experienced that many maintenance activities are not a result of diagnosed shortcomings, but that they often consist out of repairs. These more or less ad hoc repairs will not follow a defined process in which a broad scale of alternatives are weighed, but just need instant guidelines. The investments, that follow out of repairs or recognized shortcomings, need a methodology that encompasses the five kinds of information in the methodology of Santamouris et al. (1994) and that is easier to apply than the existing methodology incorporated in TOBUS of Caccavelli & Gugerli (2002) for example. Therefore, an assessment framework was developed that consists of four components.

2.1 *Description of the building*

In this component the utilization, functional design and magnitude of the building are derived. The most important variables to get acquainted with the building and to relate its performance on energy use, water consumption, and facility costs, are: the year of completion, its location, the number of employees, the number of workplaces, the number of full time equivalents, the gross floor area, the net floor area and the rentable floor area. These figures will form the base for further analysis of the object.

2.2 *Qualitative analyses of the building's sustainability*

The applied sustainable techniques or design methods are categorized by using a triad approach for five aspects, namely the Trias Energetica for energy use, Trias Hydrica for water consumption, Trias Hylica for applied materials, Trias Toponoma for land use, and Trias Poreutica for transport (Brouwers & Entrop 2005). These five aspects all contribute to the environmental impact of a building, but it is not necessary to compute the exact environmental impact of every measure within each aspect. The triad approach offers a three step sequence in creating a sustainable built environment to which the applied measures can be assigned: (1) Measures to reduce the consumption of or demand for the specific aspect; (2) Measures that fill in the remaining demand with sustainable or renewable sources as much as possible; (3) When there is still a need for more sources, then apply measures that use unsustainable sources in an efficient way.

2.3 *Quantitative analyses of the building's consumption patterns*

In the third component of the assessment framework the energy use and water consumption of the object will be assessed. Derived data are compared with performance indicators for the average Dutch energy use per square meter of offices larger than 10,000 m^2 and water consumption per employee and workday.

To assess the water consumption of the building two different indicators can be used. The assessment computer program Greencalc takes an average water consumption of 24 to 50 litres a workday for each employee into account (Van der Linden et al. 2000) and a national guideline mentions 20 to 30 litres per workday for each employee (SenterNovem 2006).

The energy use for heating is in the Netherlands normally expressed in cubic metres natural gas with an average caloric value of 33.41 MJ/m^3. The indicators for energy consumption are based on two Dutch studies (see Table 1). The first study was executed among thirty-three offices of more than 10.000 m^2 in the period 1989-1993 (Novem 2003). In 2003 a second study examined thirty-two offices larger than 10.000 m^2 (SenterNovem 2006).

Table 1: Energy consumption of Dutch office buildings for the top twenty percent, the median, and lowest twenty percent of the observations (Novem 2003, SenterNovem 2006).

Type of office	Natural gas consumption ($m^3/(m^2\cdot year)$)			Electric energy use ($kWh/(m^2\cdot year)$)			Number of objects	Year of research
Percentage of observations	20%	50%	80%	20%	50%	80%		
Offices > 10,000 m^2	5	11	16	36	82	146	33	‘89-‘93
Offices > 10,000 m^2	6	60	114	8	79	140	32	2003

2.4 *Financial analyses of the facility costs*

The facility costs of the research objects are benchmarked to assess if certain sustainable measures are preferable from a cost-effective point of view. The used reference for this benchmark was provided by the database FACANA, which is a contraction of FACility ANAlyses. The database was developed by Twynstra Gudde in 1991 and has been regularly updated ever since. Nowadays it contains the facility costs of more than 200 Dutch organizations. The offices have a total floor surface of more than 4,800,000 m^2 (Janssen & Konickx 1991).

The costs per workplace are by Facana divided in two categories: (1) object related facility costs and (2) organisation related facility costs. The costs per workplace in the first category increase, when the number of employees increases. The organisation related facility costs per workplace decrease, when the number of employees increases. Only for the second category of costs there seems to exist a quantum advantage.

3 DESCRIPTIONS OF THE CASE STUDY OBJECTS

To test the assessment framework three case study objects were selected within the tertiary sector. The objects needed to be larger than 10.000 m^2. This size was given by the already mentioned standard norms of SenterNovem. A second selection criterion was that the objects needed to be of almost the same age, because of time depending building regulations.

The selected case study objects are all three located in The Netherlands and were completed in the nineties of the last century. Although building regulations required a minimal Energy Performance Coefficient for offices from the beginning of 1995 (Official Journal 1995), it was only the required minimal thermal resistance of 2.5 $(m^2{\cdot}K)/W$ for the building shell originating from 1992 that could have been of influence on the building plans of the two youngest objects (Building Code 2003). The building and renovation activities on the second case object started in 1989, therefore its building shell has a higher thermal transmittance than the two other case objects. General information for this first component of the case study has been brought together in Table 2.

Table 2: General information on the three case objects derived in the first component of the framework.

	Object 1	Object 2	Object 3
Year of completion	1995	1993	1996
Location	Utrecht	Rotterdam	Hengelo
Number of employees	1,200	1,000	600
Number of workplaces	1,320	1,050	640
Number of full time equivalents	1,150	950	550
Gross floor area	37,890 m^2	26,918 m^2	16,087 m^2
Net floor area	34,664 m^2	22,314 m^2	14,725 m^2
Rentable floor area	30,439 m^2	18,258 m^2	13,500 m^2

The floor area of the objects can be obtained unambiguously by using standard determination methods (NNI 2001). However, only for the second object an official report was available on the size of the floor area. In the Netherlands it is common practice to offer a rentable floor area of 85 or more percent of the gross floor area (Van der Woude & Pijpers 1997), but all three objects have a smaller rentable floor area of respectively 80.3, 67.8, and 83.9 percent.

4 QUALITATIVE ANALYSES OF THE CASE STUDY OBJECTS

The three office buildings were analysed using a qualitative approach based on the five aspects of the triad approach. The results of these analyses are shown in Table 3. It can be noticed that of all aspects energy receives the most attention, although the use of sustainable or renewable energy sources is limited.

One measure regarding the Trias Hylica has a paradoxical contribution to the objects' sustainability. Using a dynamic no break system to guarantee the power supply will result in a higher electric energy use than a static no break system. On the other hand a static no break system uses batteries with a high environmental impact compared to using a fly wheel. In this case it is assumed that the environmental impact of batteries overshadows the extra electric energy use. Therefore these techniques are considered to be materialistic measures and not energetic measures within the Triad approach. The application of measures to come to sustainable water consumption, transport, and land use is limited for all three steps of the triads.

Table 3: Applied sustainable measures within the objects categorized according to the triad approach.

Trias	Step	Object 1	Object 2	Object 3
Trias Energetica	1	-Transformers for electric energy are on top floor	No measures applied	-Heat recovery by using heat wheels
	2	-Climate windows	-Natural day light in the entrance by using a mirror	No measures applied
	3	-EFF1 engine air treatment -Elevators return electric energy to the network -Mechanical valves within central heating system -External heat delivery to heat the object -External heat delivery to boil water on three floors	-Energy saving lights in restrooms	-Individual possibilities to regulate room temperature Energy saving light bulbs
Trias Hylica	1	-Flexible division of office space	-Flexible division of office space	-Flexible division of office space
	2	No measures applied	No measures applied	No measures applied
	3	-Reuse of art within façade -Reuse of cooling liquid -Dynamic no break system	-Reuse of the construction originating from the fifties -Dynamic no break system	No measures applied
Trias Hydrica	1	No measures applied	No measures applied	No measures applied
	2	-Green roof with sedum	No measures applied	-Semi-hardened parking lot to absorb rain
	3	No measures applied	-Reuse of cooling and humidification water	No measures applied
Trias Poreutica	1	No measures applied	No measures applied	No measures applied
	2	No measures applied	No measures applied	-Bicycle shed employees
	3	No measures applied	No measures applied	No measures applied
Trias Toponoma	1	-Semi-underground parking space	No measures applied	No measures applied
	2	No measures applied	No measures applied	No measures applied
	3	No measures applied	No measures applied	No measures applied

5 QUANTITATIVE ANALYSES OF THE CASE STUDY OBJECTS

This part of the assessment makes it possible to look at the energetic and water performance of the objects and their employees. The smallest actual natural gas consumption can be found at the smallest object valuing 6.2 $m^3/(m^2 \cdot year)$. Object 1 consumes 8.1 $m^3/(m^2 \cdot year)$ of natural gas. Object 2 consumes 7.0 $m^3/(m^2 \cdot year)$ of natural gas. The standard value of 60 $m^3/(m^2 \cdot year)$ (SenterNovem 2006) seems to be too high compared to the findings in this research and compared to the standard of 11 $m^3/(m^2 \cdot year)$ (Novem 2003). The actual natural gas consumption of the case objects almost equals this last standard value.

In Figure 1 degree days and actual energy use for heating are brought together. In 2004 and 2005 the difference between case 1, 2, and 3 seems to be constant. In the year 2006 the energy use of case 2 rose significantly. Although the outside temperature was lower than the temperature in the preceding two years, it is hard to relate this higher energy consumption solely to that fact.

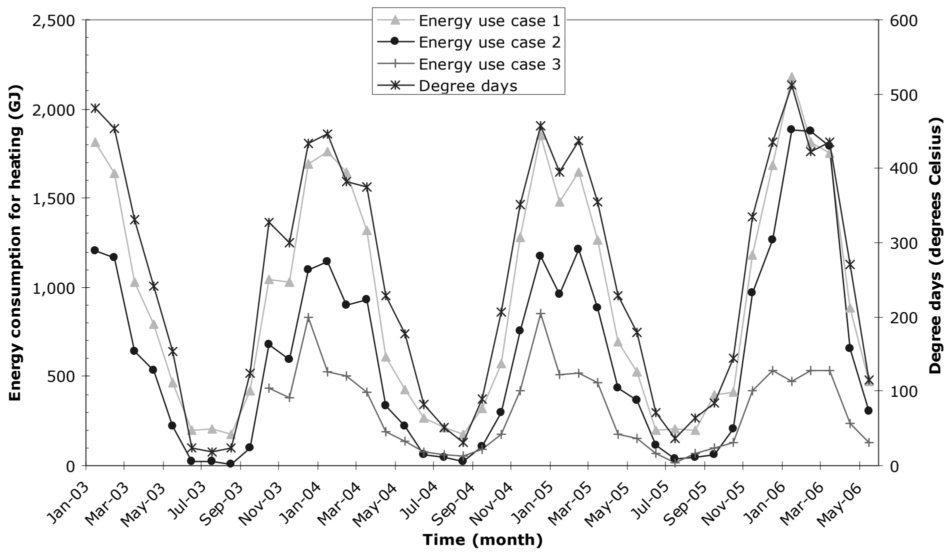

Figure 1: Monthly energy use for heating per object in relation to monthly Dutch degree days.

The natural gas consumption per employee shows a different order in efficiency than the natural gas consumption per square meter. The second case object uses less natural gas per employee than the third case object during several months in 2004 and 2005. The natural gas consumption per employee of the first object exceeds the natural gas consumption per employee of the two other case objects. The higher natural gas consumption of object 1 can be explained, because of the presence of a large auditorium and an entrance with a larger volume than case object 2 and 3.

The real electric energy use of case 3 approaches with a value of 80 kWh/(m^2·year) the mentioned standardized values of SenterNovem. The electric energy use of case 1 of 162 kWh/(m^2·year) is exceeding these values. Case 2 uses with 23 kWh/(m^2·year) only a fraction of the standard electric energy use. The monthly electric energy use is during the year more stable than the monthly natural gas consumption (see Figure 2). The electric energy use of object 1 exceeds the standard value with 100 %. Case 2 is supplied with over 600 electric heaters, but only in 2006 the electric energy increased presumably to come to a comfortable indoor temperature.

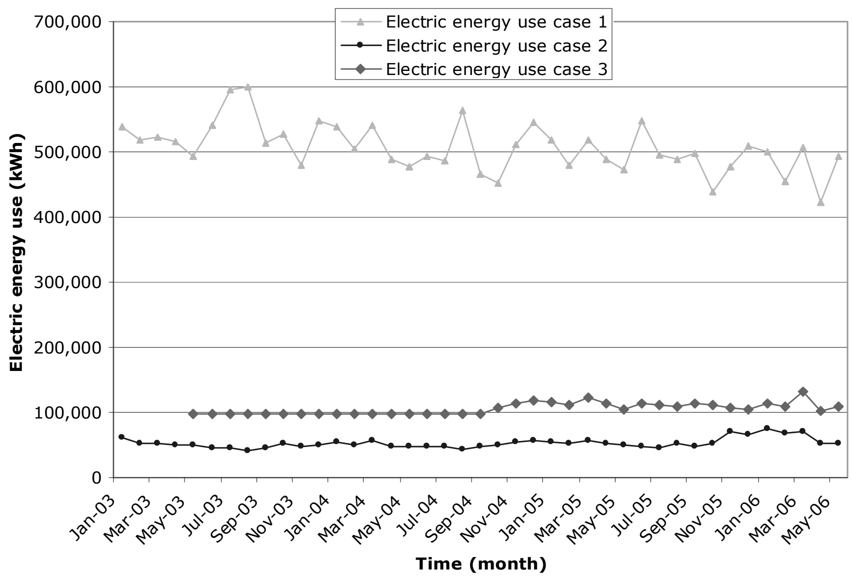

Figure 2: Monthly actual electric energy use per object.

The monthly electric energy use of case 3 was not known till September 2004 and therefore the yearly electric energy use given by the energy bills was divided by twelve. When the data on the electric energy use are corrected for the number of workplaces, employees, and full time equivalents the values per case change in proportion to each other, but the hierarchy in efficiency does not differ.

The water consumption of the cases is according to the standardized values of SenterNovem related to the number of workdays and employees. The largest object consumes annually 8000 m^3 water, but it has not the highest total water consumption. Case 2 and 3 are exceeding the average values on water use with their water consumption of respectively 10,000 and 5000 m^3/year. The consumption of case 3 is nearer to the average theoretical value than case 2. The monthly water consumption of each of the objects is strongly fluctuating (see Figure 3).

The figures per employee and per square meter gross floor area show that object 2 has the highest consumption and object 1 the lowest. With approximately 250 workdays a year the water consumption differs from 26.4 to 41.8 liter/(person·workday). Per square meter the water consumption ranges from 209 to 389 liter/year. The range of the standard values of 20 to 30 liter/(person·workday) (SenterNovem 2006) seems to small. Values of Van der Linden et al. (2000) better match the results of the case study.

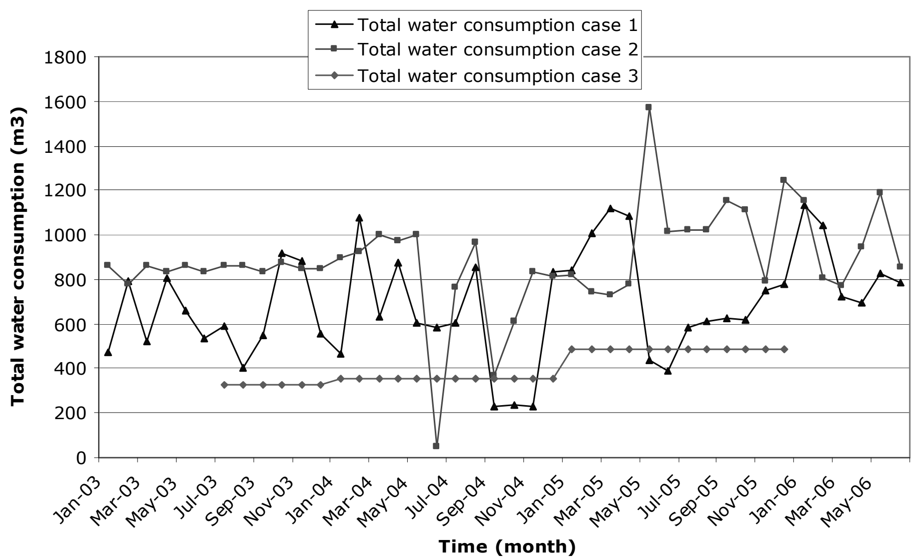

Figure 3: Monthly water consumption per case object.

6 FINANCIAL ANALYSIS OF THE CASE STUDY OBJECTS

The financial analysis is performed with help of the Facana benchmark. By giving the number of workplaces this benchmark tool is able to calculate the facility costs of one workplace and per square meter. The Facana benchmark uses for its computations a standard gross floor area of 28.7 m^2 per workplace, before calculating the costs per square meter. Case 2 and 3 offer a gross floor area of approximately 25 m^2 per workplace. The expectation is that this will result in lower actual object related facility costs than the facility costs calculated by Facana. The actual size of a workplace in object 1 equals the standard size of a workplace in Facana.

In case of object 1 the total annual facility costs are € 14,920 per workplace. A workplace in object 2 costs € 14,701 per year and in object 3 € 14,370 per year. In general the total theoretical facility costs per workplace are increasing when the number of employees is increasing. The costs on energy use and water consumption account with an absolute value of approximately € 14.90 for 4.7 to 5.8 % of the object related facility costs. The total object related facility costs are, according to Facana, around € 280.- /(m^2·year). Depreciation and mutations account for seventy to eighty percent of the object related facility costs.

The actual facility costs were derived for two objects in 2002. That year the facility costs for case object 1 were € 18,210,000.-. The expenses on the second case object were € 9,513,000.-.

For the third case the actual facility costs were not available yet. For this object it was only possible to fill out five of the twenty cost subjects that form the total facility costs. The total costs on taxes, energy use, water consumption, refurbishment, maintenance activities, and insurances were in 2006 € 1,727,000.-.

Analysis of standard facility costs and actual facility costs showed that financial benefits of energy and water saving measures can only influence a marginal part of the total building related facility costs. The direct building related costs like depreciation and mutations are accountable for 70 to 80 % of all building related facility costs. Regarding this composition of the costs, sustainable measures that increase the market value of an object or that make the object more flexible in adopting future mutations, have a potential to be cost effective.

7 DISCUSSIONS

In this paper a new framework was presented to obtain favourable investment opportunities regarding building related sustainable measures for the facility management of commercial real estate. New components in this framework are qualitative analyses and financial analyses.

The first component summarises general information on the object. In the case study information on the capacity of the heating and ventilation systems was derived, but inventories on energy consuming office equipment were not made. In future case studies these inventories should be made offering the possibility to estimate the application composition of the total energy use.

Observed sustainable measures can not be compared directly regarding their environmental impact by using merely component two, because of the narrative character. This component offers only the possibility to make a categorical inventory of the sustainable measures by distinguishing five different triads with three degrees of sustainability each. Therefore, it provides the opportunity to organise past investments and future investments opportunities more quickly.

The third component uses at this moment data, which are only referring to two of the five triads within the second component. The land use, generation of transport, and material use of the object have not been discussed by using data. Different Life Cycle Analysis methods already exist to assess material use, but the environmental impact of commercial real estate by its land use and by its generation of transport offers opportunities for further research.

The financial analyses were in this research based on the methodology of Facana. It was not an easy task to compare the theoretic facility costs and the actual facility costs of the case objects, because of different accounting methods and cost specifications. To compare the theoretic data of Facana and the actual financial data of the facility management in more detail, future research will focus on the accounting methods and the classification methodologies of the facility costs.

8 CONCLUSIONS

Three case objects that offer almost the same accommodation and that were constructed in the same decade, were analysed by using a new assessment framework. Despite the similarities, some important differences were found regarding their sustainability, energy use, water consumption and the composition of the facility costs.

The natural gas consumption for heating was with values of 6.2 to 8.2 $m^3/(m^2 \cdot year)$ found to be significantly lower than the standard reference value of 60 $m^3/(m^2 \cdot year)$ established in 2006. The actual electric energy use of the objects ranges from 23 to 162 $kWh/(m^2 \cdot year)$. The referred electric energy use is 79 to 82 $kWh/(m^2 \cdot year)$. The actual water consumption was 26.4 to 41.8 $dm^3/(person \cdot workday)$.

The use of the qualitative and quantitative analysis for assessing the sustainability of the three objects made it possible to recommend measures, which prevent energy use and water consumption, and make the energy supply and water consumption more sustainable than in the current situation. These recommendations fit in other words the first and second step of the Trias Energetica and the Trias Hydrica. The scope of this research did not allow the researchers to formulate recommendations that contribute to the goals of Trias Hylica, Trias Toponoma, and Trias Poreutica.

The proposed assessment framework makes it possible for facility managers to derive investment opportunities that contribute to a lower environmental impact of existing and new commercial real estate. The fourth component of the framework can be used to specify investments that lower yearly facility costs. The energy use and water consumption are accountable for €14 to €16/(m^2·year) of the total facility costs of € 258 to € 292/(m^2·year). Investments that contribute to the market value or flexibility of an object seem to have a higher potential in saving costs. The financial appreciation of the energy and water saving aspect of sustainable measures alone, will in some cases not suffice in expressing the real financial value and potential of these measures for the organisation that owns or uses the object.

When the framework is used for designing new buildings historical data will not be available, but by using the reference data guidelines are offered to come to designs that are more environmental friendly and have on average lower annual facility costs.

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REFERENCES

Brouwers, H.J.H., Entrop, A.G., 2005, *New triplet visions on sustainable building,* Proceedings 2005 World Sustainable Building Conference, September 27-29 2005, 18-005: 4330-4335, Tokyo (Japan)

Building Code (In Dutch: Bouwbesluit), 2003, *Hoofdstuk 5 – Voorschriften uit het oogpunt van energiezuinigheid* (In Dutch), (In English: Chapter 5 - Regulations on the energy use)

Caccavelli, D., Gugerli, H., 2002, *TOBUS- a European diagnosis and decision-making tool for office building upgrading*, Energy and Buildings 34: 113-119

Campbell, J., 1988, *Use of passive solar energy in offices*, In: P. O'Sullivan, *Passive solar energy in buildings*, The Watt Committee on Energy, Elsevier Applied Science Publishers

European Council (EC), 2002, *Energy Performance Building Directive (EPBD),* Directive 2002/91/EC of the European Parliament and Council of 16 December 2002 on the energy performance of buildings

Janssen, L.H.J.M., Konickx, J.G.F.M., 1991, *Het vergelijken van kosten van facilitaire diensten is eindelijk mogelijk! De structuur van een databank* (In Dutch) (In English: It is possible to compare costs of facility services! The structure of a database), Facility Management Magazine, October 1991: 18-21 (updated database at http://www.facana.nl)

Linden, K. van der, M. Spiekman, I. van Gaalen, M. Haas, P. Koster, 2000, *Greencalc; een calculatie- en communicatiemiddel om gebouwen meetbaar en vergelijkbaar te maken* (In Dutch), DGMR Advising engineers, The Hague

McNicholl, A., Lewis, J.O., 2001, *Energy efficiency and solar energy in European office buildings: amid-career education initiative*, Energy and Buildings 33: 213-217

Nederlands Normalisatie Instituut (NNI, English: Netherlands Normalisation Institute), 2001, *NEN 2580 Oppervlakten en inhouden van gebouwen - Termen, definities en bepalingsmethoden* (in Dutch), (English: Areas and volumes of buildings - Terms, definitions and determination methods), ICS 01.040.91

Novem, 2003, *Cijfers en Tabellen* (In Dutch), (In English: Figures and Tables), 1 KPGE 03.17

Official Journal (In Dutch: Staatsblad), 1995, *Besluit van 1 augustus 1995, houdende vaststelling van het tijdstip van inwerkingtreding van het Besluit tot wijziging van het Bouwbesluit inzake energieprestatie* (In Dutch), no. 383, ISSN 0920-2064

Santamouris, M., A. Argiriou, E. Dascalaki, C. Balaras, A. Gaglia, 1994, *Energy characteristics and savings potential in office buildings*, Solar Energy 52(1): 59-66

SenterNovem, 2006, *Cijfers en Tabellen 2006* (In Dutch), (In English: Figures and Tables 2006), 2KPGE 06.01, in order of the Netherlands Ministry of Housing, Spatial Planning and the Environment

Woude, D.H.J. van der, Pijpers, I.R., 1997, *1 Bouwnijverheid - Inleiding* (In Dutch), (English: 1 Building Industry – Introduction), series of Jellema Hogere Bouwkunde, edited by Bonebakker, M., Flapper, H.A.J., Hofkes, K., Tol, A. van, ISBN 9021290480

Life Cycle Assessment of a tourism resort with renewable materials and traditional construction techniques

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ABSTRACT: Project developments for tourism resorts or hotels often endanger an untouched or sheltered landscape. The described project is situated along the Atlantic coast in the middle of Portugal on a 1350 ha protected area, whereby 200 ha are opened for commercial use and 33 ha of the site should be used as building area. By using the appropriate method of the integrated LCA during the design process the environmental benefits for the whole life cycle of such buildings have been made transparent. The advantage of the use of traditional materials and construction techniques is shown by the low environmental impacts and high thermal efficiency in summer and winter climate. The element catalogue shows different types of constructions with their energetic and environmental performance and this information is the basis of the decision for investors, the design team and the buyers.

1 INTRODUCTION

Besides energy performance, environmental performance aspects have become more and more important criteria for the choice of constructive solutions and the development of new products. There have been several independent initiatives within the European community to develop methodologies for the declaration of environmental information that supports the construction of sustainable buildings. In addition, calculation models have been developed or are under development for the assessment of the environmental performance of complete buildings, based on an aggregation of the environmental performance of its components. These buildings should provide all of the necessary functions to the users whilst minimizing their environmental impacts. Standards are established in Great Britain (BREEAM), in France (HQE), in Italy (Itaca), Switzerland (UBP), Netherlands (GreenCALC) and Austria (TQM). These standards can be considered as innovative, although the presented results differ widely. In the background the standards are partly or completely referring to the work of ISO/TC 207 and the issues identified in ISO 14020 and ISO/TR 14025. This information is based on the ISO 14040 series of standards and the quantified environmental data for products. All of the national programs have been based on Life Cycle Assessment (LCA). The European research project "Inter-comparison and benchmarking of LCA-based environmental assessment and design tools" performed in PRESCO aimed on a clearer view on the precision of the different tools and some harmonization regarding LCA based assessment of buildings.

During the design phase of a tourism project in Portugal there have been a number of questions about a construction draft which uses traditional materials like clay, brick, cork and wood:

- What are the environmental benefits of such buildings?
- Do the constructions support a friendly indoor climate with low energetic amount?

• Which role embodied energy play?

To answer these questions it is necessary to dispose of an appropriate method (integrated LCA), relevant tools and well documented, realised buildings. The following contribution is based on the presentation of German integrated LCA software

2 LEGEP – A TOOL FOR THE ASSESSMENT OF INTEGRATED LIFECYCLE PERFORMANCE OF BUILDINGS

LEGEP is a tool for integrated life-cycle analysis resulting from basic research in Germany, Switzerland and France. It supports the planning teams in the design, construction, quantity surveying and evaluation of new or existing buildings or building products. The LEGEP database contains the description of all elements of a building (based on the German DIN 276 standard which can be mapped to other similar standards); their life cycle costs (LCC/WLC based on the German DIN 18960 and the final report EU-TG4 LCC in Construction). All information is structured along life cycle phases (construction, maintenance, operation (cleaning), refurbishment and demolition). LEGEP establishes simultaneously and for the whole life cycle

- the energy needs for heating, hot-water, electricity (following German standard EnEV and EN 832)
- the construction, operation (energy, cleaning etc.), maintenance, refurbishment and demolition costs
- the environmental impact (effect oriented evaluation based on ISO 14040 – 43) and resource consumption (detailed material input and waste).

LEGEP is organized along four software tools, each with its own database. The method is based on cost planning by “elements”. The database is hierarchically organized, starting with the LCI-data at the bottom, building material data, work-process description, simple elements for material layers, and composed elements like windows, and ends with macro-elements like building objects. The data are fully scaleable and can be used either “bottom-up” or “top-down”.

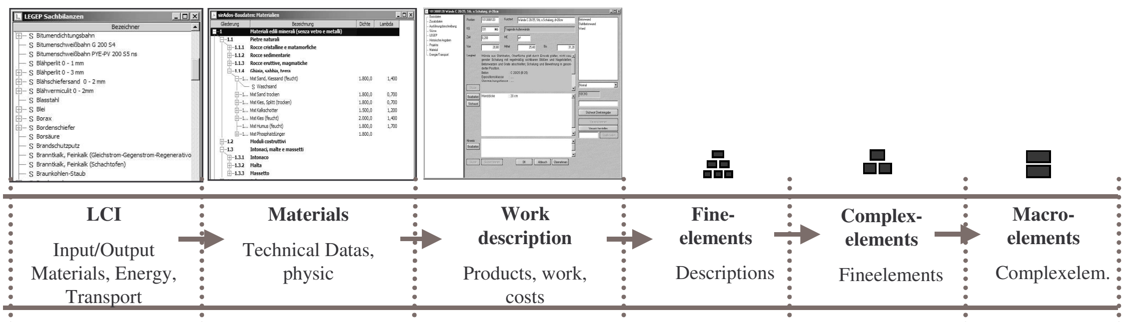

Figure 1: Hierarchical organization of data “Staircase” in LEGEP

Elements at each level contain all necessary data for cost, energy-, and mass-flow and environmental impact evaluation. A building can be described using either preassembled elements or defining elements from scratch. The user can also define a specific composition by exchanging layers or descriptions of the element. The advantage of the top down approach is its completeness: if an element is not explicitly changed or eliminated it will remain in the calculation. The costs of the elements are established by the German SirAdos database, which is published each year. There are about 8.000 elements “ready for use” for the building fabric, technical equipment and landscape work. The LC Inventories are based on the ECOINVENT data and specific values from the Baustoff Ökoinventare and a LEGEP database with specific values for construction products.

3 THE PROJECT COSTA TERRA

Costa terra is a leisure development near Grandola, Portugal. It is situated less than 130 km south of Lisbon along the Atlantic coast on a 1350 ha protected area, whereby 200 ha development area are opened for commercial use and 33 ha of the site should be used as building area.. The project includes 3 suite hotels, 4 tourism villages, 4 apart hotels, 1 inn, 204 villas and 1 golf course.

During the early design stage more than 130 projects and studies of different technical fields, involving more than 70 consultants with 300 specialists, were delivered and ended in a quality certification system concerning forest, environment, health and safety. One part of the environment quality management following EN ISO 14001 is the construction regulations. These regulations have adopted a set of principles and rules, within its "Building Code" that derive from traditional building technologies. The regulations include a list of recommended materials like clay, wood and cork, authorised materials (concrete for primary structure), forbidden materials (e.g. concrete roofs, metal tiles) and a catalogue of recommended construction elements.

4 CONSTRUCTION LEVEL - COMPARISON OF CONSTRUCTIONS

For the design phase of a project the comparison of LCA-Data of building materials, e.g. 1 t of concrete compared with 1 m³ of wood, is not helpful. For architects and planners it is recommended to start the comparison on the construction level. The work shall consider the following steps:

- Definition of the functional unit e.g. 1 m² of outside wall
- Definition of the technical performance of the construction e.g. u-value or fire resistance.
- Definition of the service life of the construction, e.g. 80 years
- Definition of the ecological indicators, e.g. CO_2 –eq.,SO_2 –eq.
- Selection of the constructions to be compared

4.1 Description of the constructions

The architects present a set of recommended constructions, Type A and Type B, Type C is not recommended, but serves as a reference model. Type A uses traditional materials and techniques e.g. a wall of rammed earth. Type B uses traditional materials but combines them with industrialized techniques e.g. a wall with layers from low-weight clay stones and porosized bricks. Type C uses conventional materials and technique e.g. reinforced concrete and synthetic insulation material.

Table 1 Overview of wall and roof constructions

Construction	Type A		Type B		Type C	
	Layer	Thick-ness	Layer	Thick-ness	Layer	Thick-ness
		cm		cm		cm
Outside wall	Clay color		Natural-resin based color		Synthetic based color	
	Clay plaster	1,5	Lime-plaster	1,5	Cement-lime-plaster	1,5
	Clay	50	Low-weight clay stones	11,5	Concrete column	25
	Wood-fiber-board	6	Porosized brick	24	Light weight bricks	25
	Lime-plaster	2	Lime-cement-plaster	2	Cement-plaster	2
	Silicate-		Silicate- color		Synthetic resin	

	color				based color	
Roof	Gypsum board	2	Wooden beam	18	Synthetic resin based color	
	Wind barrier		Wooden board	2	Lime cement plaster	1,5
	Wooden beam	18	Wind barrier		Concrete slab	20
	Cellulose fiber	18	Cork insulation	8	Bitumen based coating	0,4
	Wood fiber board	2	Cement fiber board	0,8	Polystyrol- insulation	10
	Brick tiles		Brick tiles		Cement tiles	

The list of proposed constructions encloses

- Foundations
- Outside walls, windows and doors
- Inside walls and doors
- Ceilings and staircases
- Roofs

The technical equipment is described without alternatives. Based on these data the constructions were modeled within the database.

4.2 Results

The case study evaluates three sets of constructions. The evaluations include

- the energetic and
- the environmental performance.

The energetic performance compares the behavior of the construction during the winter (U-value) and the summer period (, phase displacement, effective storage mass).

Table 2 Overview of energetic performance of the wall and roof constructions

Construction			Type A	Type B	Type C
	Indicator	Unit			
Outside wall					
	U-Value	W/m²K	0,47	0,78	0,85
	Phase Displacement	h	21,6	13,9	10,3
	Effective storage mass	kg	936	350	140
	Temperature-Amplitude Damping	1/TAV	702	19	14
Roof					
	U-Value	W/m²K	0,28	0,44	0,36
	Phase Displacement	h	10,4	6,9	8,7
	Effective storage mass	kg	27	22	502
	Temperature-Amplitude Damping	1/TAV	15	5	104

The constructions Type A proof a good profile for both periods. This will support the thermal comfort of the user inside the building and reduces the need of air-conditioning.

The environmental performance compares the following indicators:

- Climate change, kg CO_2-eq./m²
- Acidification, kg SO_2-eq./m²
- Primary energy non renewable, MJ/m².

The impacts can be calculated for the construction phase (see figure 2 below) or for the whole life cycle (e.g. 80 years).

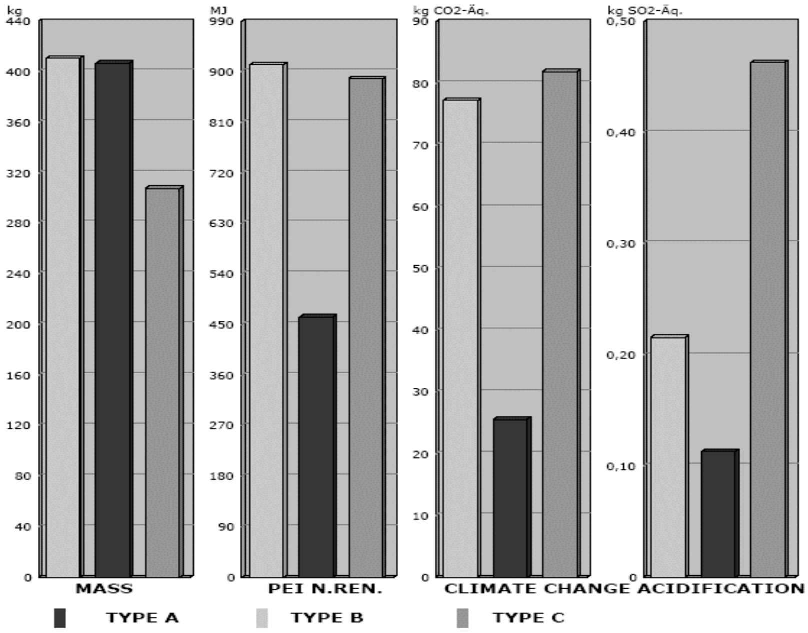

Figure 2: Overview of environmental performance of the wall constructions

The construction Type A (red) show low environmental impacts due to the use of materials which have a very low prefabrication level and are put together on the construction site e.g. the rammed earth walls. The other construction elements (windows, ceilings, roofs) show similar results. The aspect of a higher amount of working time or the aspect of dependency of sunny weather periods is not taken into account.

5 BUILDING LEVEL

The building is the source of local, regional and global environmental impacts. The functional equivalent of a building on which the building assessment is based, is derived from the project specification of the building. The building, including its foundations (optional the external works within the area of building site) is the object of assessments and the source of impacts over its life cycle. The physical and temporal system boundary for the assessment shall be defined in the scope of the assessment. The results of the assessments are expected to provide the means for understanding the impact that the building and its site have on the environment and on the user.

This case study is concerned on the analysis of the impacts of the building over its life cycle (80 years) including processes and services related to the building life cycle.

5.1 *Description of the building*

In the northern part of the area 3 suite hotels (Gross floor area 33.600 m², Volume 78.450 m³) are planned in form of a serpent which surrounds a courtyard.

The building is described in the software with three sets of construction elements Type A, B and C. Only a small part of the results is presented here, trying to show the difference between the conventional buildings and the building using traditional construction methods.

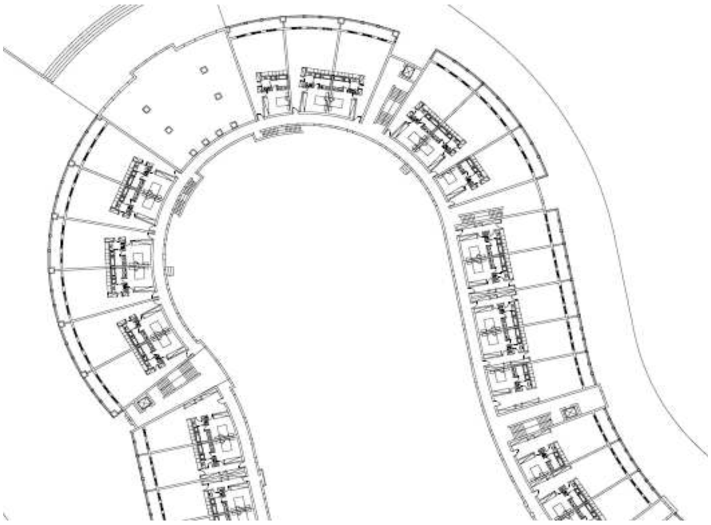

Figure 3: Suite Hotel, First Floor

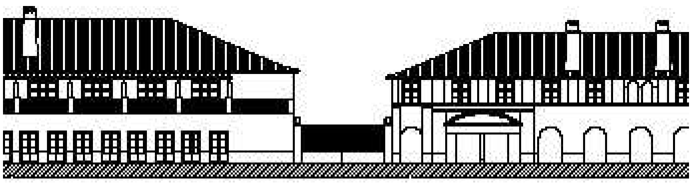

Figure 4: Suite Hotel, Facade

5.2 *Results*

For the evaluation and comparison of the three buildings in a first step only the construction over the life cycle (80 years) excluding operational energy use is analyzed.

As assumed the building with the construction set Type A shows the lowest environmental impacts over its life cycle.

In a second step the three buildings are evaluated including the operational energy use. It is known that the operational energy use for the life cycle of 80 years contributes in Germany about 80 % to the use of primary energy of the building. In Portugal, due to other climate data the influence of the heating demand is reduced but the need of air-conditioning increases the use of electricity during the summer period. To compare buildings in both climates data are lacking.

To show the influence of alternative solutions the three buildings were modelled with different technical equipment:

Type A: heating with wood, solar panels for hot water (30%), no air conditioning
Type B: heating and hot water with gas, photovoltaic for production of electricity (30%), no air conditioning
Type C: heating and hot water with oil, 100 % air-conditioning.

The calculation is based on the German standard, EnEV modified with climate data of Portugal. The heat demand of the three buildings varies within a corridor of 20% due to the different constructions. The calculations are modified in a second step with special data for the need of hot water and electricity in a hotel. The influence of these consumptions on the environmental impacts is more than 60%. In a third step the above mentioned strategy for different technical equipments was introduced in the buildings Type A and Type B to lower the energy amount without reducing the comfort level. For the calculation of the environmental impacts of electricity the average European mix (UCPT) is used.

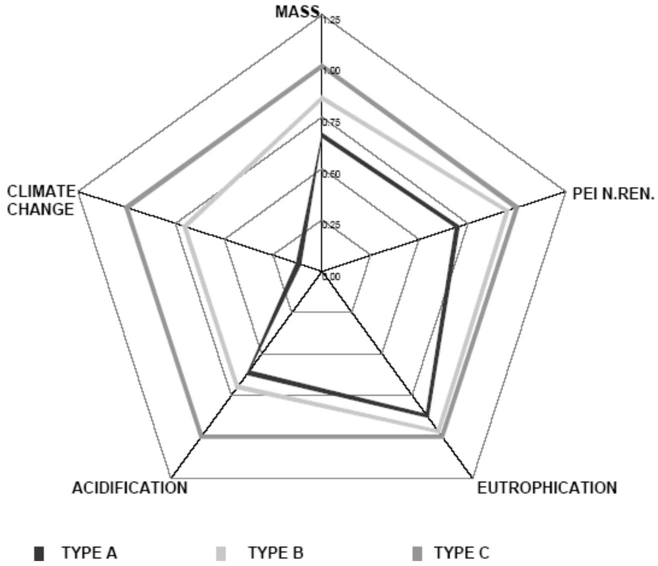

Figure 5: Comparison between "traditional" (Type A), "modified traditional" (Type B) and "conventional" (Type C) building, excluding operational use of energy

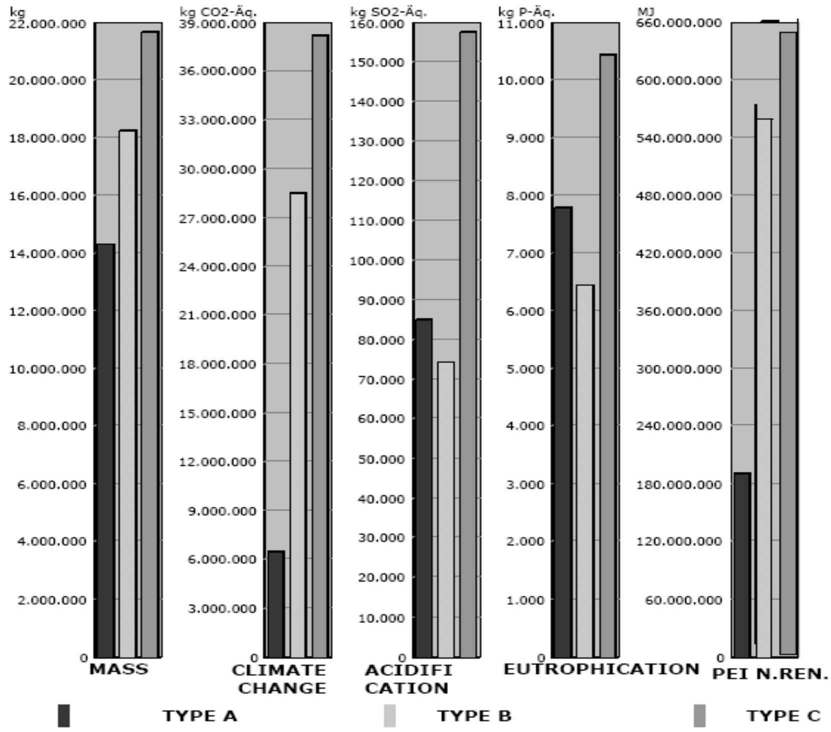

Figure 6: Comparison between traditional (Type A), traditional-modified (Type B) and conventional (Type C) building including operational use of energy over the life cycle (80 years)

The building Type A (red) shows the lowest impact for CO_2-eq. and primary energy but higher impacts for SO_2-eq. and PO_4. This results from the heating with wood. Type B shows the lowest impact for SO_2-eq. and PO_4 due to the production of 30% of the electricity demand by means of photovoltaic.

6 CONCLUSIONS

LCA-Tools which remodel buildings at different stages of their life cycle with a scaleable database of elements and processes – like LEGEP – allow a complete evaluation of buildings with reasonable amount of work. Through the use of LEGEP the main effort of the designers and other specialists is shifted from the extremely cumbersome description of a building and extensive input of data into a specific software to the interpretation of large number of synthetic results at each moment. The combined effects of changes can be immediately visualized; new methods of design can be founded on experience gained from LCA knowledge. In detail:

1. The advantages of traditional materials and constructions can be quantified by using the method of integrated Life Cycle Analysis.
2. To support the decision process of architects the work must be based on the definition of the functional and technical equivalent to allow a comparison of different constructions.
3. The effective storage mass of traditional wall and ceiling constructions allows avoiding the air conditioning of the indoor climate and supports the reduction of the environmental impacts of the building.
4. The combination of traditional constructions and modern technical equipment shows clearly the advantages in the short and long term run.

The constructions Type A are still in use today in small residential houses. To adapt these methods in the tourist sector for hotel buildings, the environmental friendly profile of traditional architecture can enlarge the idea of personal wellness to the contribution of a sheltered environment. In this case the LCA can support the marketing ideas of the investor.

REFERENCES

DIN 276, 1993 „Kosten im Hochbau“ (Cost Estimation for Construction Works) Deutsches Institut für Normung, Berlin

DIN 18960, 1999, „Nutzungskosten im Hochbau“ (Service Life Costs in Construction Works) Deutsches Institut für Normung, Berlin

ENEV, 2004 “Energieeinsparverordnung” (Energy-Saving-Decree), Bundesgesetzblatt Jahrgang 2004, Teil 1 Nr. 64, Bonn, 2004

Kohler N., Wagner A., Luetzkendorf T., König H., 2005 „Life cycle assessment of buildings with LEGEP® - a LCA-tool from Germany”, Tokyo

PRESCO, 2004, WP2, final report, Intercomparison and benchmarking of building related environmental assessment and design tools, Paris

UCTE Union for the Coordination of Transmission of Electricity see also: http://www.ucte.org

A sustainable planning design tool for the environmental compatibility of the tourist coastal territory

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ABSTRACT: This research deals with the general discussion about the *environmental impact of tourism* (a multidisciplinary issue concerning environment, society, culture and economics) and focuses on the degradation caused by the building activity and by the tourist facilities development on unprotected territories of coastal areas. These areas are affected by great tourist flows that have positively effects on local economy in the short-time, are attracted by the environmental qualities, but cause the deterioration of the natural ecosystem with the anthropic pressure. The final goal of this work is to define a support tool for the planning to a sustainable approach. This tool can be used by local authorities that realize sustainable planning interventions in the Mediterranean coastal territories, where the tourist demand is limited to a short-time, and it can be used by the authorities in the evaluation phase of the projects, and by the architects for the preliminary design as well.

1 INTRODUCTION

Tourism is a worldwide phenomenon, it has impressive dimensions both considering the number of people involved and the aspects concerned by, and therefore it cannot be regarded as a sole economical activity: it is a possibility of contact, comparison, growth, an effective way for the cultural, social and economic local development.

In many cases, the results of policies aimed at a short-term and forced growth of the tourist activity, lacking a careful planning, have been the cause of environmental disasters. The growth of tourist coastal centres followed similar development processes: at the beginning, the tourist demand was attracted by the quality of the landscape, producing an increase in the tourist facilities - which, without an environmental control, started deterioration processes of the environment– and a transformation of the tourist demand from a naturalistic demand, into a recreational one. At the same time, the increase in the local economy produces a transformation of the economical activities typical of the territory into tourist activities. In the long run, these process leads to the loss of the local identity of an area and to the abandonment of the urban centres during the period in which the tourist demand is absent.

1.1 *Background*

In 1978, in order to face the environmental impact of tourist activities, WTO (Worldwide Tourism Organization) established an environmental committee, which gathered for the first time in Madrid in 1981. However the concept of sustainable tourism was coined only after the more general definition of sustainable development. “The sustainable development of tourism shall meet the need of tourists and of all the destinations, at the same time, improving and enhancing the future possibilities”; this definition was set only in April 1995, at the end of the First Worldwide Summit on Sustainable tourism, in Lanzarote (Canary Islands), where the World Chart of

Sustainable Tourism were drawn up. Sustainable Tourism is not restricted to be only responsible tourism, eco-conscious visitors, eco-hotels, etc., it also deals with environmental protection and sustainable planning.

In many cases, for example, the deterioration and the consumption of the land (one of the resources with the slowest re-formation rate) persists in the name of a tourist demand, which is limited only to three/four months a year.

The tourism must be considered a transversal activity that promotes and improves the qualities and the peculiar economic activities of the territory and is a base of its development.

1.2 *The goal*

The main objective of this study is to define a sustainable planning design tool, specific for coastal tourist planning.

HQE^2R (Haute Qualité Environnemental et Economique pour la Réhabilitation) is a European methodology for sustainable neighbourhoods regeneration, that in this research it was adopted as a reference.

2 METHODOLOGY

The present research has used the methodological structure of HQE^2R, the output result structure, whose efficacy has been extensively tested, has been used as well.

The basic phases are: realization of the document related to the inventories and the *diagnosis protocol*; definition of the system of specific *indicators* for the existing conditions evaluation, and definition and evaluation of hypothetical development *scenarios*. Like HQE^2R also this tool has the output file like a radar graphic, the vertexes are the systems of indicators (families), measured through a scale of values from +3 to -3. Every system of indicators is determined by the calculation cards of specific indicators scientifically measured. The tool measures the indicators families that are called the "specific objects". In these kind of tools, the final result is comparative and not quantitative: the mathematical operation to lead back the different parameters to unique value scale points up the harmonic relations between the indicators families: the harmonic degree is an indispensable parameter for the sustainability evaluation of the general system.

In this case, the systems analyzed are: the *user system* (all the users of the communal territory in the year -residents and tourists); the *territory system* (the urban, natural and cultivo areas); the *services system* distinguished in resident and tourists services; the r*esources system* measures of consumptions in "open cycles" (consumption of no recycled water, consumption of no-self production power and production of no recyclable waste) of both resident and tourists.

The processes of definition of the indicators and their method of calculation have been fundamentals. The following main families of indicators have been established: 1. preservation and enhancement of the local values [*territory*]; 2. protection of the resources through the reduction of the open cycle consumption [*resource*: energy $KgCO_2$/mq , water resources Liters/person day, urban waste Kg/person/day]; 3. *services* improvement [service: quality of life and quality of the visit]; 4. "tourist pressure" ratio improvement: *residents/visitors* ratio [the ratio among users typologies], this objective, defined as δ_T visitor/(resident + visitor) will help to understand the "threshold level" of the pressure.

The definition of the specific objectives, referring to this decision-making support tool, is originated from the analysis of the diagnosis protocol and of the development processes occurring in the coastal areas of the Mediterranean region. In this case the calculation cards of the indicators families (the specific objects) are elaborated to make it easy the introduction of the data in the future applications. The data will have to be modified according to the requirements and the local peculiarities. In this type of planning tools, the transparency of the final result is fundamental and represents a synthesis of the processes applied for the environmental evaluation.

2.1 *The final output chart.*

The configuration of the final chart, according to the four objectives established, is represented by the following figure:

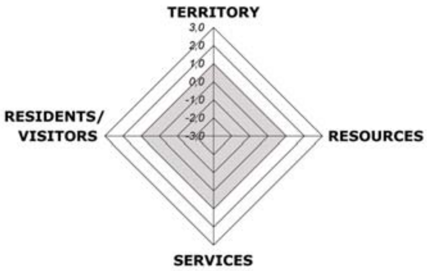

Figure 1: output chart

3 THE FIRST CASE STUDY

The first experimental application was made on the territory of Porto Cesareo in the province of Lecce, situated in the South of Italy.

Porto Cesareo is characterized by peculiar environmental elements, subject to seasonal tourist flows; in the last decade the tourist demand had an exponential growth, therefore the setting up of tourist facilities has been increasing. The expansion of the built areas generally takes place with low attention to the techniques for environmental protection. The area has more than 20km of coastline and it is in the coastline of the Ionian Sea (Sea of the Gulf of Taranto), about 40° parallel.

Figure 2: Porto Cesareo: municipal area and pictures.

Half of the borders of the municipal area of Porto Cesareo, are in the coastline of the Mediterranean Sea. It is a tongue of land extending for about 3500 Ha, which in the narrowest points is only 900 meters deep. The maximum height of small hills in the inland is 50 meters sloping gently down to the sea.

At the present time, there are in the area 18 hotel structures, 3 guesthouses, two holiday villages and a campsite. All the accommodation typologies are in expansion; above all the taken area of the holiday villages has almost doubled in the last five years.

In 2002, the number of the homes was to 16.856 of which 14.829 holiday homes: this data are not always expressive the truth, but gives a flash of the problem dimension.

3.1 *Methodology for the evaluation of the objectives.*

The writing out of the diagnosis protocol is necessary to highlight the basic characteristics of the whole area under consideration.

In this case, users are divided into five main categories: the criteria to distinguish the five categories are "use span" and "use kind" of the area, according to the visitors and residents needs. The five user categories are: *resident*; *owner visitor 1* (continuative presence, throughout 4-5 months a year, and during weekends in winter); *lodger visitor* 2 (presence shorter than the previous category, concentrated in the holyday season months, over a period of 2-3 months every year); *weekly visitor 3* (periodical presence a few weeks/years in the summer period [they use hotels, guesthouses and camping sites]; *daily visitor 4* (generally by car, their presence is spread over 3-4 months; on the coastal areas only).
In particular the resources consumptions and the quality of the services were analyzed for each the five user categories.

Resources-The resources evaluation can be carried out through the measurement of their consumption; the indicators help the evaluation of the use of open-cycle resources, an element which automatically gives information on the no sustainability of a system. This objective especially measures the impact that building has on the available resources within a region. Generally consumption is divided in three main classes (as already explained in the diagnosis phase): 1. energy consumption [*$KgCO_2/m^2$*]; water consumption [*litres/person per day*]; waste production [*Kg/ person per day*]. To evaluate this specific objective it is necessary to analyze the consumption referred to each user typology in order to calculate the final consumption rate related to three consumption categories, as show in the following figure:

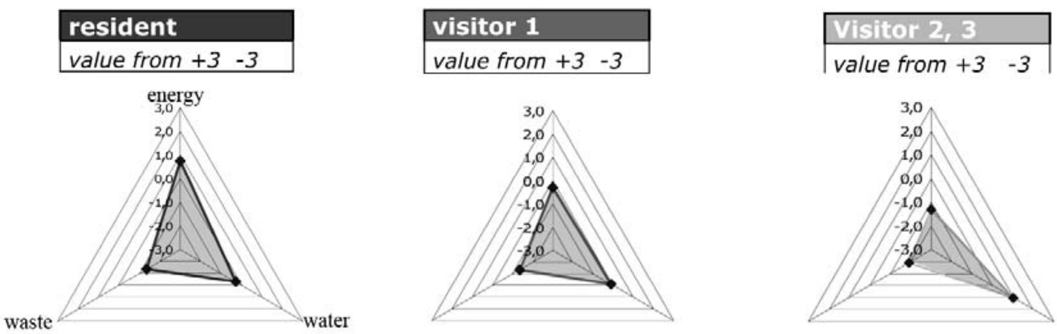

Figure 3: Resources Evaluations

The chart, which summarizes the consumption of the different users, points out that the more critical aspect is referred to the consumption of water. The data analyzed suggest that Visitor 2 and 3 are the biggest consumption of water; this kind of user is hosted in hotels, holiday villages and guest-houses.

Services- In the diagnosis protocol, a few main service categories have been defined, as follows: school services, leisure-cultural activities, commercial and health-related services.

During the evaluation of the services, a series of specific indicators will be added to each class of services. The values assigned to each specific indicator are based on the following function: Σ (*fx*) =*f*(X) +*f*(Y) +*f*(J) where X= number or frequency; Y= accessibility, J= functionality

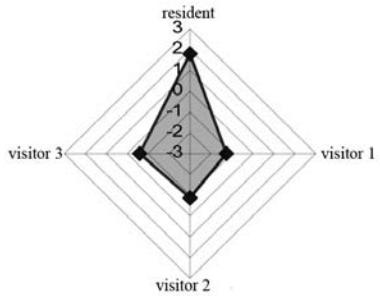

Figure4: Services Evaluations

Observing the results achieved, it is clear that the worst level of services is offered the *visitor 1* (owner of holiday homes). This is due to the holiday homes location, often far away from the available services. This is also one of the main causes of environmental deterioration. For the same reason the visitor 1 who uses the services needs generally to use private transport, hardly replaceable by alternative means.

Territory- In the diagnosis protocol, the six land typologies have been determined: *natural vegetation areas, traditional cultivation areas, generic cultivation areas, dense urban areas, thin urban areas and areas with thin building* (in this area the holiday homes were built during last 50 years). These five territorial classes refer to two important macro-categories: *green areas* and *built areas.*

	land type		ha	existing condition %	scenario1 %	scenario2 %	scenario3 %
green areas	natural vegetation areas	HR	62	2%	2%	2%	2%
		MR	96	4%	4%	4%	4%
		LR	138	6%	6%	6%	6%
		N	264	11%	11%	26%	11%
	traditional cultivation a.		263	11%	26%	18%	11%
	generic cultivation a.		456	18%	16%	16%	18%
built areas	dense urban a.		260	10%	10%	10%	10%
	rade urban a.		263	11%	4%	9%	11%
	tourist a. (visitors 1)		687	28%	21%	8%	28%
			2.489				

Figure5: Territorial valuation

Since the object of this research is the environmental compatibility, the natural vegetation areas were the most analysed and they divided in four subclasses:

I group HR (high rate) high-quality habitat. Optimal evaluation: in this areas there is a connection among the areas with a high quality habitat; they are surrounded by medium quality habitats (ecological connected corridors);

II group MR (medium rate) medium-quality habitat: small clustered high quality patches, not fully connected. The corridor is composed by areas with variable quality, but surrounded by low quality habitats. The corridor could also be fragmented, and surrounded by medium quality habitats/settlements;

III group LR (low rate) low-quality unsuitable habitat: the corridor is surrounded by low-quality habitats, such as completely impervious land, or the corridor is intersected by medium quality habitats, therefore improvements are possible. Otherwise the corridor does not exist, but the area around the green patches is medium-quality, thus the areas are possibly connectable.

IV group N (negligible): large and completely impervious land intersects the corridor. Otherwise the intersection has small dimensions, but the green patches are surrounded by low quality habitats, therefore unlikely to be connected (Forman, 1995).

The result of the existing condition, equal to -1, is indicative of a critical state. This negative value assumes higher importance, if we consider that Porto Cesareo is the target of a tourist demand attracted by the seaside resorts, which are strictly connected to the natural environment.

Resident/visitor ratio: this ratio, defined as δ_T *visitor/(resident +visitor)* and originated by variable "time", corresponds to the pressure ratio of a visitors over a residents. In this case the availability for the evaluation data are partial and not fully objective. The unique analysis refers to a statistical survey carried out in August 2005. The final result is then absolutely questionable and shows several contradictions compared with other analysis. However, the pressure ratio is not alarming also considering that Porto Cesareo is a tourist site undergoing an exponential growth/expansion.

3.2 *Results*

The evaluation of the existing conditions shows that both the values referring to the consumption of the *resources* and the *territory* rate are below zero. These results show a critical condition that point up most urgent problem of this territory. The evaluation of the existing conditions is the essential starting point to define the hypothetical scenarios of development, in according with the local authorities policies.

*Scenario 1: Building of two new tourist accommodation building center, located along strategic road junctions. Construction of an urban free zone, near the beach, set up as a traffic restraint area***.** For the good functioning of this scenario, the construction of the new buildings must follow all the low-consumption and low-environmental impact technologies. Since these are new buildings it is possible to obtain the best orientation, apply low-energy consumption systems and specific systems for collecting and recycling meteoritic waters. The public spaces built, in this scenario, will be of the pervious land and natural vegetation.

The output result obtained by the evaluation of this scenario shows that the specific objective concerning general quantity/quality of the *services* has notably improved. This scenario acts only on the lodging visitor and weekly visitor. In regard to the results concerning the pressure *resident/visitor* and the *resources* consumption, it is possible to note that in both cases there is a slight improvement compared whit existing conditions. Since two tourist units have been designed to accommodate the flow of visitors flocking to the area, the pressure level is changed. It is necessary to note, however, that from a social and cultural point of view, such a scenario does not stimulate the interactions between residents and visitors, and the social and cultural benefits that a resident may have from such exchanges will be inhibited.

Scenario 2: Renovation of the existing houses and demolition of the areas in the most critical conditions; controlled construction of new urban spaces and connection with green areas (ecological corridors). In order the renovation of the local urban structure to optimize the use of the resources. Construction of an urban free zone, near the beach, set up as a traffic restraint area. This development scenario conceives a careful and precise analysis of the built area; and then the each action of retrofitting must maximize the high efficiency level and values the consumption resources and the comfort level, in the built environment.

Observing the final output result, it is possible to note a general improvement, especially concerning resources consumption and services evaluation. This scenario acts on the all users; in particular it acts on the reduction of the resources consumption by residents and owner visitors. These users stay in the area in the long time and use. The improvement reported by the values concerning *resources* and *services* is notable; the *resident/visitor* value is little changed in comparison to the existing conditions.

Scenario 3: Complete renovation of all the existing buildings and redevelopment of selected areas. Construction of an urban free zone, near the beach, set up as a traffic restraint area. The actions are limited to the renovation of the existing built of the urban centre, but in this scenario is not forecast demolition action.

The improvement reported by the values concerning resources and services conservation is sufficient in this scenario. The improvement reported by the values concerning *resources* and *services* is notable; the *resident/visitor* value is unchanged in comparison to the existing conditions.

In all scenarios are forecast a series of bicycle rental points, with electrical bikes, will be set-up in the beach area, like alternative means of transportation. The points will be located at a distance of 500 meters from one another (distance which can be covered to walk).

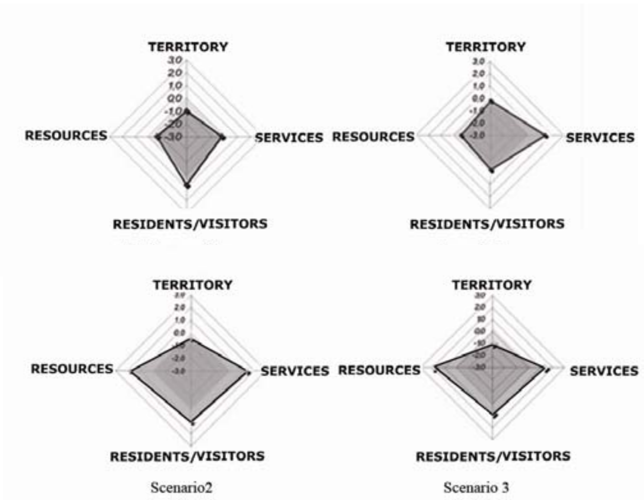

Figure 6: Final Evaluations

The comparison of the final charts related to the existing conditions and the development scenarios clarifies that the area represented in these diagrams is wider than that considered in the existing conditions (this is especially evident in scenario Two and Three).

3.3 *Result comparison*

The first critical point, detected by the comparison among the existing conditions and the different scenarios, is the difficulty to increase the values of the *territory*. Therefore, although both scenarios 1 and 2 envisage local changes, they can’t assign a value above zero to the territory. This is due to the general difficulty to regenerate the degraded green areas. The natural land is a resource with the slowest reformation rate. The third scenario does not envisage any demolition and the evaluation of the area is unchanged, compared with the existing conditions.

Following there are the comparison graphs of the annual consumptions. We can read as changing the consumptions in the different scenarios.

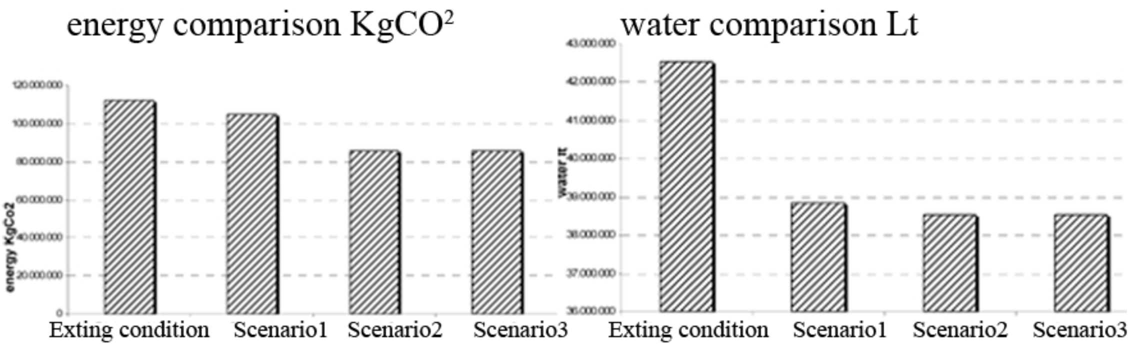

Figure 7: The comparisons

4 CONCLUSIONS

This tool puts in systemic relation some territory indicators with building environmental indicators, evaluating the possible planning actions starting the building scale: the sustainability evaluation of the system cannot be limited to the building scale.

Being aware that the environmental evaluations and the sustainability development analysis are only "flashes" of a dynamic system continuously evolving, this study looks a methodology for the evaluation of the environmental impacts on the coastal territory, with special attention to the Mediterranean regions. The first research results are not exhaustive of environmental issues of the coastal tourist centers, but are a contribution for the definition of the support tools to the sustainable planning and the integrated management of these particular areas.

The first tool application has pointed out its limits and its potentialities: this tool focuses on the compatibility of the built environment and its hypothetical development. The scenarios are calculated on a period of 20 years, but this time isn't enough for the renovation of the natural land resource. In fact, the three scenarios don't increase the rate of the HR (high rate) MR (medium rate) and LR (low rate) territory. Only the scenario 2 increases the N (negligible rate) from the 11% to the 26%.

In this application the data referred to the resources consumptions are not specific of Porto Cesareo. Aware that it would have been favorable to have the local data, it has been considered suitable to continue the experimentation with the acquired data, because one object of this experimentation was to construction the tool's structure to be tested on other territories.

The basic step, in this research, has been the definition of indicators useful and the measurability of the scientific problem. The processes of indicators definition and their calculation method have been fundamentals. In this tools kind, the final result legibility is essential.

Aware that the application to unique case study is not enough, we propose a future application of this tool on other case studies. The further tests will offer the possibility to sharpen the measurability systems to improve the level of final result.

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6 REFERENCES

-Deliverable 10, *HQE2R Methodology for sustainable neighbourhoods regeneration* (2003).

-Forman, *Land Mosaics-The ecology of landscape and regions*, Cambridge University Press (1995).

-Georgescu- Roegen Nicholas, a cura di Bonaiuti Mauro, *Bioeconomia verso un'altra economia ecologicamente e socialmente sostenibile,* Bollati Boringhieri Editore (2003).

Building deconstruction in Portugal: a case study

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ABSTRACT: This paper presents the transfer and adaptation of the former Lisbon EXPO 98 Macao Pavilion from its original location to a town park in Loures as a case study in building deconstruction. An essential aspect for promoting Building Deconstruction is the demonstration of its multiple advantages, mainly to those directly involved in the designing and building processes, proving the compatibility of deconstruction friendly principles with architectural expression, functional efficiency and economical profitability. A description of the disassembly and reassembly operations of the former Macao Pavilion is made, identifying the main difficulties found. An analysis of the overall profitability of the operation is also made, estimating the amount of material diverted from landfill and the amount of embodied energy saved through material reuse. An economical profitability study compares the costs of disassembling and reassembling the pavilion with those of a new building.

1 INTRODUCTION

Portugal is currently facing serious challenges to its production and consumption habits. The country is very dependent on imports for its energy needs, with 87,2 % of the national yearly consumption deriving from external sources (DGEG – Geology and Energy General Directorate, in Portuguese, 2005), and energy efficiency is 25% above European Union's average with 240 kgoe/1000 Euros in 2004 (EUROSTAT, 2004).

The building construction industry, one of the largest employers in the country, is also considered a major responsible for several negative environmental impacts: energy consumption, associated emissions and waste production. Although the exact amount of construction and demolition waste (CDW) produced each year is not known, estimates point to a value of 4,4 Million tons (Farinha, 2007), the vast majority of which is land filled or illegally dumped. This value of CDW production may be attributed to lack of awareness, lack of other processing options and prevalence of construction habits that do not allow material separation or reuse. In this context, it is urgent to adapt design and construction paradigms to achieve greater resource use efficiency, reducing the amount of embodied and operational energy and also increasing the diversion of CDW from landfills.

Building Deconstruction emphasizes promotion of "reuse" of building materials and components (and even whole buildings) as a way to "close the loop" of materials, and avoid the loss of matter and energy through construction and demolition waste. Whole building reuse is an example of Deconstruction, by disassembling a building and transferring part or the whole of its components to a new site for reassembly. Such operations are quite rare in Portugal and the opportunity to follow and fully document the transfer of the former Lisbon EXPO 98 Macao Pavilion was considered a good subject for a case study in Deconstruction, as it would allow evaluating its environmental and economical profitability.

2 BACKGROUND

The Lisbon Expo 98 Macao Pavilion was designed by RISCO architectural design office in 1997 and was built in the northern central part of the EXPO 98 exhibition grounds, alongside the main pedestrian avenue, on a rectangular eastern facing sloping plot surrounded on three sides by streets while the north side opened to a another building plot (Figure 1).

Figure 1: The former EXPO 98 Macao Pavilion (Southeast view) in its original location in May 2005.

The Pavilion was a two-story building, with an doubly symmetric 55 x 30 meters rectangular shaped plan, comprising two "blocks" with two floors each. The eastern block housed exhibition spaces and was open at the street level, while the western block also housed exhibition spaces and administration / reception areas in the enclosed lower floor. Both upper levels were linked by two partially enclosed elevated walkways, which defined a patio between both blocks. The whole building had a structure of bolted metallic elements ranging in cross-section from HEA 600 to IPE 200, with enclosing walls made of 22 mm thick wood-cement viroc panels supported by metallic frames bolted to the main structure, except for the lower western block which had a brick encased metallic structure and brick partitioning walls. The floor of the upper level was made of 3 cm thick Medium Density Fiberboards and solid pinewood boards, while the roof was integrally made of corrugated metal panels, with metal rain gutters and eaves. Interior finishes (ceiling and walls) were gypsum board drywalls, including 60 mm rock wool insulation. The upper volumes had no windows, the only glass being present on the doors and panels that enclosed the street side of the elevated walkways. Windows and doors on the lower volume were double-glazed and aluminum framed. After the exhibition's end in October 1998, the pavilion was vacated and closed. In late 2004 it was bought by the Loures municipality to be reassembled in the new town park of Loures and used as a teahouse / art gallery.

3 DISASSEMBLY

Disassembly started in May 2005, taking place in three main stages over a period of approximately 14 weeks up to mid-August 2005. During the first stage, interior finishing materials were stripped, sorted by type and piled on the elevated walkways since the patio was unavailable as a sorting and stocking point. Building systems were also disassembled at this time. Doors, hardware, fixtures, cabling and piping were removed for reuse or recycling. Metals (soft steel, copper wiring) were sold to scrap metal dealers; wooden materials were removed to be used as fuel; other materials (rock wool, gypsum) were land filled.

The second stage of the disassembly took about four weeks and consisted on the dismantling of the building's external envelope, made possible since the removal of the interior finishes had exposed all of the internal connecting points for the external façade support frames as well as the roof panel's fixings. At this point, unfamiliarity with disassembly operations led to time losses as some elements were "over disassembled" rather than kept as whole components, while there was no properly established identification system for the parts.

The third stage of the process consisted on the disassembly of the steel structure. All of the elements of the steel structure were bolted, which allowed and facilitated disassembly, and were of a manageable size, which allowed manipulation and transport with commonly available means. The external access ramp, composed of two 24 meter long trusses, had to be cut in two for transport, while the main pillars bolting plates were found to be encased in concrete, and had to be cut making. A final step of the disassembly process consisted on the demolition of all reinforced concrete (foundations, ground slab and retaining wall) and brickwork walls.

In conclusion, the configuration and constructive solutions, such as assembly sequence, geometry of product edges and connection methods (Durmisevic, 2003) allowed for a systematic separation of building materials. A more thorough audit prior to disassembly would have identified materials, components and sub-assemblies worthy of disassembly and transport, an action that might have increased the profitability of the operation, as the value of harvested materials is usually inversely proportional to the number of disassembly steps necessary to acquire them (Durmisevic, 2006). A more effective labeling system for identifying components and their connections would also have benefited the whole operation, as it was later estimated that a more effective labeling of parts would have reduced reassembly time as much as 25%.

4 REASSEMBLY

The contract for reassembling the metal structure and build a new exterior enclosure was won by the Somague company, with reassembly started in the spring of 2006 and still ongoing in May 2007 (Figure 2). The reassembly was slowed down by a variety of factors namely because the materials transported had been piled up exactly on the building's future location alongside a general lack of information on the building design (original plans were not found on the architect's archives) and deficient or inexistent labeling of parts .

During rebuilding it was discovered that a few medium sized elements from the main structure were missing, and it was necessary to produce similar ones. New structural elements also had to be produced to replace those that had been encased in brickwork, while the original (and shortened) main pillars received new bolting plates.Other changes to the original project included the introduction of an intermediate steel deck.

Other than the structural steel elements, little was reused from the originally transported parts, either because materials had already been reused ("viroc" wood-cement panels were applied in the back facade of the St. Paul church scale reproduction), because they were unnecessary (façade substructures were not needed, as infill walls were now to be made of ceramic brickwork) or because they were unusable (asphalt contaminated roof panels).

Figure 2: General view of the pavilion being rebuilt in Loures as of April 2007.

5 ENVIRONMENTAL PROFITABILITY

Although it is fairly obvious that an operation of disassemble / reassemble should be environmentally preferable to a straightforward demolition, it is essential to determine exactly the benefits of such operations in order to promote design for disassembly and material reuse. There is no voluntary building environmental rating scheme in use in Portugal (such as BREEAM, LEED or Green Building Tool), and therefore there is no immediate methodological framework to evaluate the benefits associated with reuse of building components or materials.

Guy (2003) has proposed a Green Demolition Certification Draft, consisting of a credit system, rating actions at Building, Planning and Environmental Health and Safety levels of the demolition process. The system proposes the attribution of a green certificate on attaining 25 of the 52 possible credits, while setting minimum pre-requisites such as a mandatory 20% material diversion from landfill independently of building size. The literal application of this certification draft was deemed inadequate in this particular case, nevertheless the environmental profitability of this operation was evaluated on two of the most “valuable” rating aspects of the rating scheme: diversion of materials from landfill and embodied energy saved.

5.1 *Materials diverted from landfill*

The original complete bill of materials of the pavilion having been lost, a new bill of materials was calculated from EXPO archive project drawings and partial RISCO files. This allowed an estimation of the quantities of materials present in terms of weight, with composite elements (window units, facade panels) being broken into their main materials. Smaller components (bolts, door handles, etc.) were ignored for these calculations. Materials associated with building systems such as HVAC, rainwater drainage, water supply and residual waters were not considered given their low relative weight or impossibility to decompose into basic materials (as in the case of air treatment units).

In calculating the mass and weight of the materials, several references were used (Farinha, 1997), as well as catalogues and technical information reference material. Weights of structural elements (steel and concrete) were taken from the original structural bill of materials. The pavilion weighted a total of 1.820 tons, with 75% of that value being reinforced concrete present in foundations, ground slab and retaining walls (Figure 3).

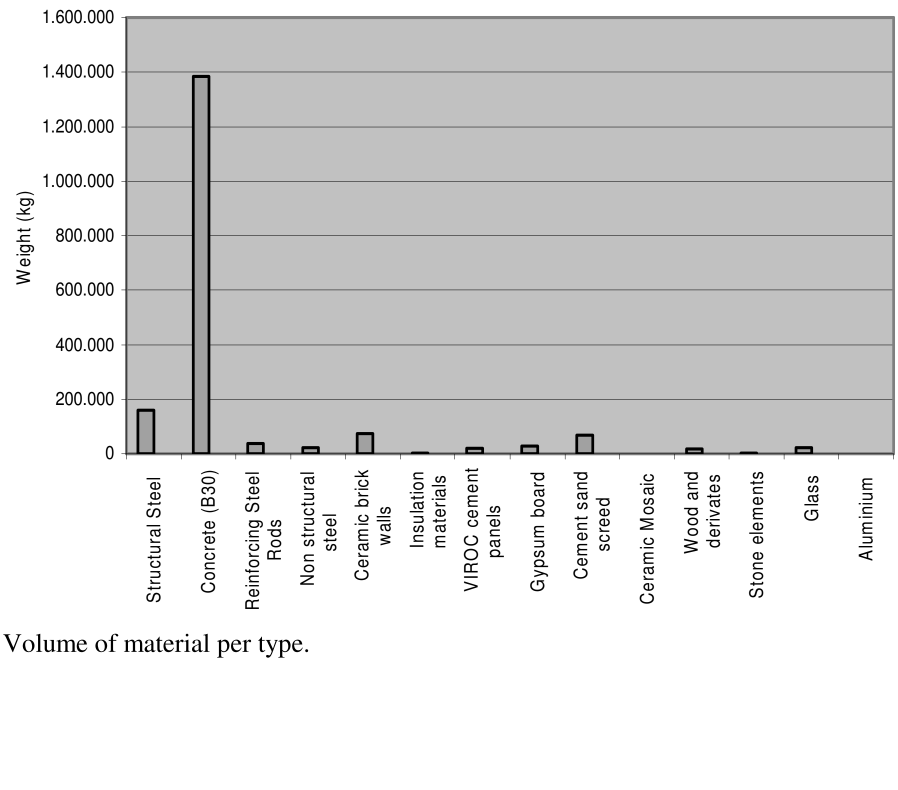

Figure 3: Volume of material per type.

Allocating the different materials per waste processing option (Figure 4), it becomes apparent that only 10% of the materials were reused (the steel structure and viroc panels), while a total of 14% were diverted from landfill (through a mix of reuse, recycling and energy recovery). While these percentages would not meet the minimum requirements of the Green Demolition Certification draft mentioned, it should be noted that almost all of the main constituting materials were adequately separated and thus the lack of a higher diversion rate from landfill could be attributed to lack of processing options and not to project or process characteristics.

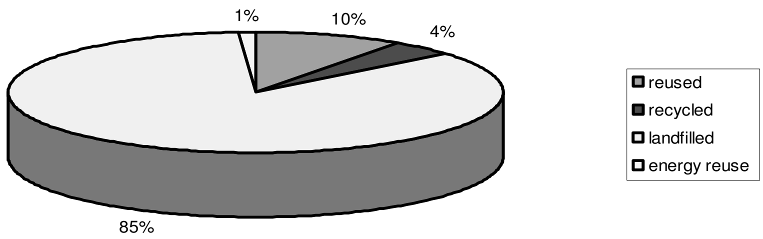

Figure 4: Volume of material per waste processing option.

5.2 *Embodied energy savings*

Another complementary assessment of environmental profitability of the transfer / rebuild operation is to quantify the amount of embodied energy saved. Treloar (1998) defines embodied energy as "the quantity of energy required by all the activities associated with a production process, including the relative proportions consumed in all activities upstream to the acquisition of natural resources and the share of energy used in making equipment and other supporting functions, i.e. direct plus indirect energy".

In the context of this study, embodied energy was understood as "process embodied energy" and not "gross embodied energy", thus excluding energy used to transport the materials and workers to the building site, upstream energy input in making the materials (such as factory / office lighting, energy used in making and maintaining the machines that make the materials, etc.) or embodied energy of urban infrastructure (roads, drains, water and energy supply). Process embodied energy values for construction materials can vary greatly since there are many different combinations of possible input / output paths to attain a certain embodied energy value per unit of material. Studies (CSIRO, 2003) have identified the following variables affecting embodied energy calculations: efficiency of manufacturing process; fuels in manufacture of materials; distances of transport and amount of recycled product used.

Embodied energy values are considered useful as an additional decision factor when comparing different building materials for a specific design problem, ideally complemented by environmental impact reference materials, since a low embodied energy material may be less favorable than another with higher energy content for a variety of reasons (lower technical service life, reciclability, etc.). Nevertheless, given the demonstrational character of this study, it was considered useful to demonstrate potential energy savings in this building transfer operation by calculating the amount of embodied energy preserved in reused building materials.

The previously calculated material volumes were converted into MegaJoules using several reference tables for embodied energy values per unit of mass. Since there are no specific embodied energy tables for construction materials in Portugal, the closest comparable source was used, namely the tables of the Spanish Instituto para la Diversificación y Ahorro de la Energía (IDAE), as cited by Gonzalez (2006). These reference values were considered to be very reliable as Spain and Portugal have similar geographic conditions, construction habits and construction material usage. In the only instance where a value for a material used in the Macao

Pavilion was not available in these tables, data from the New Zealand Institute of Architects "Comparison of building elements - Life cycle analysis" database (1995) was used. In calculating the embodied energy of steel elements a value of 14,25 MJ/kg was used, as a mean average between the values of 35 MJ/kg for virgin material and 10 MJ/kg for recycled source material considering that 83% of current steel is recycled or of recycled content (Steel Construction Institute, 2002). The original pavilion materials thus corresponded to a total of approximately 5.630.000 MJ of embodied energy, distributed according to Table 1.

Table 1: Embodied energy present in the original building, including waste processing options (RU - reused; RE - Recycled; LF - Land filled; ER - Energy recovery)

	Weight (kg)	MJ/kg	Energy (MJ)	Option
Structural elements				
Steel structural elements	159.900	14,25	2.278.575	RU
Reinforcing steel rods	38.360	10,00	383.600	RE
Concrete (B30)	1.383.120	1,20	1.659.744	LF
Exterior walls				
Perforated ceramic brick wall, 30 x 20 x 20 cm, with cement / sand mortar render	5.384	2,50	13.460	LF
Perforated ceramic brick cavity wall, 30 x 20 x 15 + 30 x 20 x 11, with cement / sand mortar render	35.148	2,50	87.871	LF
Cavity wall insulation rigid PU board (30 mm)	71	72,20	5.147	LF
VIROC wood-cement facade panels (22 mm)	18.701	9,50	177.657	RU
50 x 50 x 4 RSH facade panels metal frames	7.075	14,25	100.813	RE
Interior walls				
Perforated ceramic brick wall, 30 x 20 x 11 cm, with cement / sand mortar render	33.587	2,50	83.966	LF
Interior single 12,5 mm plasterboard wall (inc. substructure)	7.612	6,10	46.431	LF
Rock-wool insulation (60 mm thick)	1.305	14,60	19.051	LF
Floor finishings				
Cement sand screed, smooth finish (100 mm)	67.859	1,20	81.430	LF
Ceramic mosaic 10 x 10 cm	170	2,50	425	LF
Pinewood floor baseboard (20 x 70 mm section)	122	2,00	244	ER
Solid pinewood floor (30 mm)	3.936	2,00	7.873	ER
Moist resistant MDF boards (30 mm)	14.388	11,90	171.214	LF
Ceiling finishings				
Interior suspended plasterboard	9.709	6,10	59.223	LF
Exterior moist resistant suspended plasterboard	10.237	6,10	62.444	LF
Rock-wool insulation (60 mm thick)	2.459	14,60	35.905	LF
Stonework				
Door sills (average thickness 4 cm)	1.801	6,00	10.805	LF
Doors and windows				
Glass	4.720	15,90	75.041	RE
Aluminum frames	280	191,00	53.461	RE
Steel frames and doors	4.261	14,25	60.715	RE
Various steelwork				
Exterior hand-railings	1.235	14,25	17.592	RE
Roof panels, corrugated sheet metal "Alaço" type	7.809	14,25	111.271	LF
HVAC protection perforated panels, inc. substructure	1.230	14,25	17.524	RE
1 mm zinced water-drains and eaves profiles	251	14,25	3.583	RE
TOTAL	1.821.482		5.630.036	

According to the various disposal options for the different materials present in the Pavilion, it can be observed that 43% of the total EE value, corresponding to 2.450.000 MJ, was preserved due to the steel structure being reused. Considering the loss of 10-15% of the original steel components of the building, nevertheless approximately 2.200.000 MJ of embodied energy may have been saved. The production of this energy from fossil fuel would correspond to approximately 52,5 tons of oil equivalent (1 toe = 42 GigaJoules), whose combustion would release (on average) approximately 45.000 kg CO_2 to the atmosphere. The amount of energy saved corresponds to 680.000 KW/h, which would cost 75.000 Euros (at current national rates).

A comparison made using values from Portugal's General Directorate for Energy "Energy Consumption Management Regulation" (1995), which stipulate maximum tons of oil equivalent to be spent in the production of certain construction materials, yielded steel embodied energy values almost 20% higher than those obtained through the Spanish IDAE values.

As mentioned earlier the embodied energy values considered do not account for energy from transport, and so the added energy from the trips necessary to transport the pavilion steel components was not considered. However, it is important to refer that if this transport energy were accounted for, the option to reuse would be even more favorable than new building since there is no source of steel elements closer to Loures than the Expo site (the sites are just 18 km apart). CO_2 emissions and embodied energy due to transport corresponded respectively to 550 kg CO_2 and 56 MJ, from the 200 l of diesel estimated to have been used in the 20 two-way journeys to transport the structure (consumption and distance obtained in www.mappy2.com).

In conclusion, although only a low percentage of the total material volume of the existing building was reused, it did correspond to over 40% of the total estimated embodied energy present, which constituted a considerable environmental and financial saving.

6 ECONOMICAL PROFITABILITY

Parallel to the environmental benefits estimation, an equally important assessment (some would argue, the most important one) is that of the economical profitability of this operation. The Loures municipality paid a total of € 260.000 (excluding taxes) for disassembly, reassembly and construction of a new enclosure. The pavilion itself was donated, an obvious choice for the owner as the property becomes available for redevelopment at zero cost.

An economical profitability study must compare the values paid for actually (re)used elements to the value of supplying and assembling new comparable products. As seen before, material reuse was limited practically to steel structure elements, of which the original pavilion possessed 160.000 kg. Considering a 10% replacement rate for lost parts and 24.000 kg to replace the elements that were originally encased in brickwork (estimated from the original bill of materials) a total of 200.000 kg present in the new pavilion is obtained.

Considering that the value of the new foundations, enclosure walls and roof (which should be discounted) is equal to the price paid for the road transport of the elements (which should be added), an average value of 1,30 Euro paid per kg of steel is obtained.

If a fully similar building were to be built anew, the budget of supplying and assembling 160.000 kg of steel structure (the original amount needed) would be € 528.000 using 2006 average tender prices of € 3, 30 per kg of steel. If the original 198.000 kg of steel (160,000 kg from the structure plus 38.000 kg of reinforced concrete bars) had been sold for recycling, it is reasonable that a price of 0.5 Euro/kg would have been paid, resulting in a net total of 429.000 Euro to be paid for a new pavilion.

Considering both the least and most advantageous relationships between the aforementioned values, the disassemble / reassemble option is always more profitable (for the owner), with prices 65 to 100% lower than the price of an all new structure. It is interesting to consider that if a reinforced concrete structure had been used in a new similar building, the estimated cost (from average prices per sqm of construction) would have been approximately 295,000 Euro, a value still higher than the 260.000 Euro paid by the municipality.

7 CONCLUSION

Although the disassembly and reassembly of the former Lisbon Expo 98 Macao Pavilion was affected and slowed down due to the novelty of the process, the balance was nevertheless positive on both economical and environmental aspects. A low 14% diversion rate from landfill was achieved, but the materials reused amounted to almost 40% of the total embodied energy present. Economically the operation was profitable on all levels, and a more efficient planning on disassembly would have raised the profitability of the operation even further.

Studies (Boyle, 2005) have shown that transport and degree of waste processing infrastructures are the main conditioning factors to salvaged material reuse overall profitability. In the Macao Pavilion case, the very short distance between disassembly and reassembly sites reduced the negative impacts of transport, but the lack of appropriate disposal options greatly hindered the degree of diversion from landfill. This was made more evident since the original design was very favorable to deconstruction, permitting an effective reversal of the building sequence and allowing a high degree of material separation.

This operation was greatly facilitated by the fact that it was promoted by a public body which eased bureaucratic procedures, as no project and building permits were required, while the "whole rebuilding" option allowed bypassing structural calculations and verifications. A mention must also be made to the overall architectural strategy as it allowed functional adaptation with little effort, benefiting from the typology of the building (an isolated building).

This study shows that in more urbanized areas of Portugal, where building habits are more developed, more sophisticated building techniques are available and transport networks are more dense, it may prove profitable on all dimensions to design all steel structure buildings that allow disassembly and transfer, thus obtaining a higher construction material usage efficiency, and ultimately a more sustainable construction.

In order to achieve this ultimate objective, further efforts are necessary in many areas, including raising awareness of stakeholders, laying down appropriate legal framework, creating adequate processing infrastructures and raising the consciousness of designers and builders.

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9 REFERENCES

- Boyle, C., "Analysis of Dismantling vs. Demolition - Vision or Reality", 8th DBMC conference, Vancouver, Canada, 1999
- CCE, "A Gestão da Energia e o Regulamento de Gestão de Consumo de Energia", DGE Lisboa, 1995
- EUROSTAT, "Europe in Figures - Eurostat yearbook", 2006-07
- Durmisevic, E., "Re-use potential of steel building construction", CIB Publication 287, 2003
- Durmisevic, E., "Transformable Building Structures", Ph. D. Thesis, Delft, 2006
- Farinha, J.S, Tabelas Técnicas, Edições Técnicas E.T.L., 1996
- Farinha, P., "Portugal com 4,4 milhões de resíduos anuais provenientes da construção" in Público Suplemento Imobiliário, April 6th, 2007
- Gonzaléz, M., "Assessment of the decrease of CO_2 emissions in the construction field through the selection of materials: Practical case study of three houses of low environmental impact" in Building and Environment 41 (2006), 902-909
- Guy, B., "Deconstruction Certification Standard", www.decon04.com, accessed Nov. 2005
- Steel Construction Institute, "ECSC Project: LCA for steel construction" Document RT 913, version 01, July 2002
- Treloar, G., "A comprehensive embodied energy analysis framework", Ph. D. thesis, Deakin University, Australia, 1998

Impacts in the internal environment quality of a Music School from the urban design of a university campus

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ABSTRACT: This work aims to discuss the impact generated by the university campus urban planning on one of its buildings. In order to do so, the environment general comfort of the Music School at the Federal University of Minas Gerais was evaluated by collecting objective and subjective data. Results have shown that the difficulty endured by the architect is proportional to the project's dimension and complexity. It also brought light to the fact that environment comfort is considered as one of the most important factors to the user's satisfaction, regarding the space adequacy with the activities' development. Thus, project decisions turn well-aimed if both principles of Sustainability and Ergonomics are considered since the beginning.

1 INTRODUCTION

This paper aims to specifically discuss the impacts brought up by urban planning on the indoor environment quality of the Music School at the Federal University of Minas Gerais – UFMG, according to an approach with an interface between sustainability and ergonomics.

Sustainability is related to the present needs satisfaction without jeopardizing the future generations' needs satisfaction, in an economic, social and environmental sphere. It emphasizes the care with the planet and with the natural resources preservation, since they will not last forever. Regarding architecture, sustainability can focus on the buildings' environmental quality, whatever their nature is.

By considering a school building sustainability, which is our case study, it is important to have a harmonious relation between the building and its surroundings. This means that a school project should be created considering the exterior characteristics of its context and not as an isolated object (Azevedo et al, 2005). Therefore, one should not deny the climate characteristics surrounding the building implantation and the architectonic characteristics that agree with its function. These should provide comfort to the user through the proper utilization of architectonic devices and architectonic techniques and materials (Gaudin & Bastos, 2006).

Environmental comfort's goal is to promote comfort in the building's indoor environment and its surroundings, having the thermal, acoustic, air quality, light, visual and "ergonomic" aspects in mind. Ergonomics is closely related with environmental comfort. After all, its goal is to set men comfortable during the accomplishment of his activities, and for that, it may contribute in the creation of a built environment adequate to its users (Castro & Rheingantz, 2006).

To foresee the future activity accomplished on the environment that still isn't conceived, it is not an easy task for the architect, during the project conception. Harder yet is to understand the way how people will act to accomplish their activities (Martin, 2000). The bigger the project scale is, the bigger is the difficulty to consider and represent all the needs regarding the users' activities. Thus, the architect macro vision, when accomplishing an urban planning, may define guidelines that instigate impacts regarding the indoor environment quality of a building, which is included in that same urban project, and consequently, conflicts with its users during the accomplishment of their activities. In order to reflect upon this theme (Vilaça, 2001), this paper will present the study case already mentioned.

2 CHARACTERIZATION OF THE STUDIED CONTEXT

According to Souza et al (1998), historically, the Federal University of Minas Gerais – UFMG – grew without a pilot organization plan and without uniformity as a university, thus having several units on the surroundings of the beautiful city of Belo Horizonte.

The idea to project a university campus at the Minas Gerais state started to be discussed on 1789, but it was only on 1945 that the actual location of the university campus was decided. The geographic region gathered the conditions considered as essential, such as the area largeness, favourable topography and tranquillity, proximity to the urban centre and transportation facility.

The project was implanted by the University Directory. Initially, the buildings followed the streets guidance determined by 45º angle and by a modular network of 120m, which occupied the entire territory. The methodological guidelines for the campus design were based on the structuralism reason, according to the technique need, represented by the method itself. Thus, the campus design neglected the environmental conditions, topography and the needs of each building. Moreover it did not represent a human centrality.

The freedom to conceive buildings and to create something different did not exist during the design process. What did exist was a system that determined every environment built. Thus, every campus building was built according to the same parameters, without considering the different specificities of each building. This is reflected on the inadequate situations of several natures, being most of them directly connected with the relation between the needs of the activities accomplished in the building and the indoor environment quality of the building.

The Music School is one of the buildings included in this context and was built 16 years ago. At the time, the project was conceived having in mind the urban project conditions, the cost so that it wouldn't transform the accomplishment inviable and flexibility. This means that should new needs arise, the project would foresee a flexible margin to operate some changes. Thus, a concrete and masonry structure was built which allowed, for instances, the classrooms' expansion.

The School building welcomes about 300 students and has approximately 5.000m2 of built area, distributed over three floors: ground floor, upper floor and down floor.

The main entrance is done through the ground floor. It has a central block and two different areas. To the left, we find the classrooms, and to the right, the administrative sector. Between the two areas, at the school centre, there is the block which includes the considered as the noisiest environments: auditorium, percussion room and the multimedia room. Figure 1 shows a floor map. The teachers' offices, the library and the IT laboratories are located at the upper floor. The canteen and some more classrooms are located at the down floor. The school implantation, according to the building longitudinal guiding east-west in order to include itself at the urban project, demanded the creation of triangular protuberances on the façades which represent the windows directions in the north-south direction, in order to reduce the thermal win and to make the best of natural lighting.

School also receives zenithal lighting over both central mezzanine to the right and left areas. Below the translucent cover, there is a brick belt which allows the exit of hot air. The mezzanine existence infers the floors inter connection and, also, of the indoor environment quality determinant factors.

School does not have thermal acoustic treatment overall. Only the central block, where the auditorium, the percussion room and the multimedia room are located, has an air conditioning system and some acoustic resources: the massive brick wall and the ceiling with a tilting movement to avoid the parallelism between the walls, the floor and the ceiling. Also, there are some sponge fill in to absorb noise.

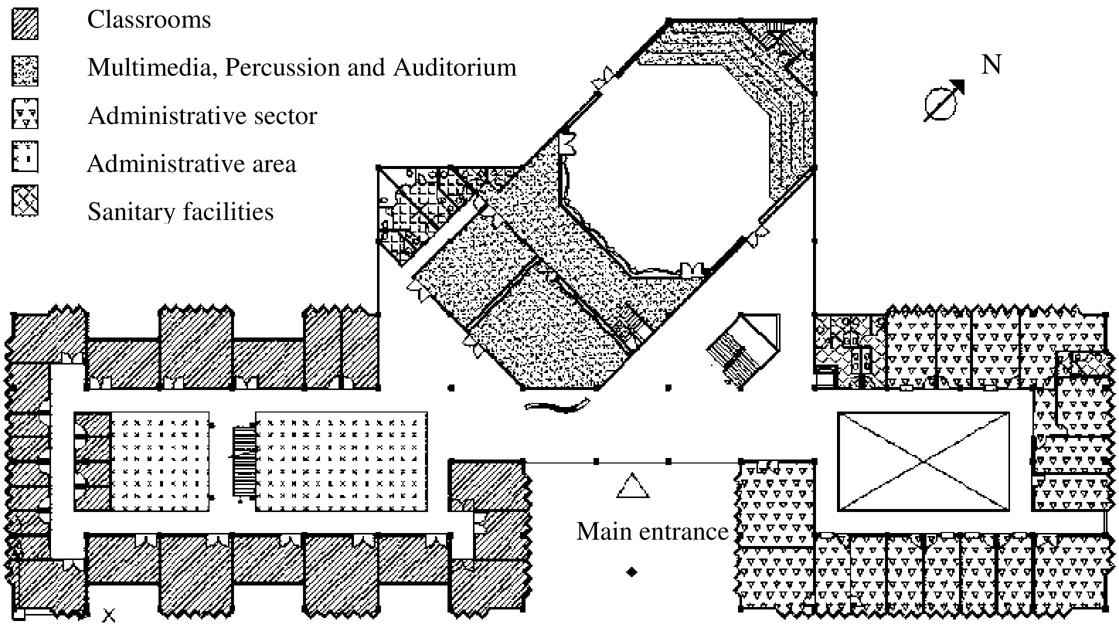

Figure 1 – Music School Ground Floor.

Nevertheless, users do not considered these actions as completely satisfactory. There are some complaints regarding the presence or absence of air conditioning. Where there is an air conditioning, the blow instruments musicians complain about the dry air and their saliva; and where it does not exist, musicians complain on the heat.

Regarding acoustic, there is a discomfort caused by the noise that moves from one room to another, which can generate some conflicts among the users. As such, they try to keep the windows and doors closed. At the rooms with no air conditioning, they feel the heat while they play and they are told to use an auricular protection against noise.

Users (teachers, students and employees) asked the Works Department of the Federal University of Minas Gerais for the improvement of the space quality. This is the main reason which made us choose this building among all other buildings to conduct this research.

3 METHODOLOGY

In order to assess the environment global comfort of the Music School, objective and subjective data was collected. The objective data refer to the measurements carried out on the building indoor environment concerning thermal comfort, noise and lighting; and also to the measurements on the outside gathered by the weather station that belongs to the university campus. The subjective data refer to the subjective perception of the school users. Initially, several open interviews (Guérin *et al*, 2001) were conducted, where users expressed their opinion regarding comfort and the building adequacy to their needs, thus helping not only to define the day, time and environment, but also to plan the acquisition of the objective data. After the measurements, a questionnaire was conducted where users should classify environmental comfort, taking the thermal environment, indoor air quality, noise, vibrations, lighting and a global discomfort level into account.

Two different sceneries were evaluated: one located at the school's central building (multimedia room), the other located outside (individual study room). The first scenario was thermally and acoustically treated but the second wasn't, just like most of the remaining parts of the building. Wednesday was the day chosen for the measurements, because it was considered to be one of the school's busiest days and also because some of the noisiest classes took place on that day. The sound emission produced during the "chamber chorus" class, the "trombone orchestra" class, "percussion groups" class, "improvisation" and "orchestra" is the one that brings more discomfort among the users that aren't participating in those same classes. One of these classes was chosen as a study case: the "trombone orchestra". This class occurs from 14:20 to 16:00 at the multimedia room. The measurements started at 14:00 and ended at 15:30.

The following equipments were used to accomplish those measurements:

a) a psycrometer "Taylor USA" and a WBGT meter Questemp 15", to measure thermal environment quantities. Both devices measured dry bulb and wet bulb temperatures, allowing the WBGT meter also the measurement of globe temperature. Complementary measurements of relative humidity were performed with a "THDL-400 environment meter".

b) a digital anemometer "Minipa – MDA-II", for air velocity measurements. Every door and window was closed, since the room is usually closed;

c) a noise dosimeter "Q-400 Noise Dosimeter Quest Tecnologies" to measure noise equivalent level. Moreover, sound frequency analysis were performed with a soundmeter "Brüel & Kjaer type 2230", with a frequency filter "Brüel & Kjaer 1625", for octave bands between 31.5 Hz and 8000 Hz

d) lighting was measured by the luximeter "Paulux eletronic 2".

Measurements were taken at the multimedia room and at the individual study room and the same devices were used in both rooms. Figure 2A and 2B shows the exact measurements' location, marked with a "x" and "y", in each room. Only the lighting measurement was made by placing the device on each side of the score.

Table 1. The main characteristics of the evaluation panel.

	Age (yy)	Height (m)	Weight (kg)	Clothing Level		Metabolic Rate	
				CLO	m^2 ºC/W	W/m^2	MET
Average	25.2	1.8	76.8	0.38	0.069	83.06	1.44
Maximum	38.0	1.9	123.0	0.44	0.083	100	1.7
Minimum	20.0	1.6	58.0	0.23	0.035	80	1.4
Std. Dev.	4.1	0.1	14.9	0.09	0.017	7.10	0.10

Questionnaire was filled in after the measurements were completed in each scenario. Thus, fifteen people (fourteen students and one teacher) answered the questionnaire regarding the multimedia room, two students filled the questionnaires in regarding the percussion room and one person answered it regarding the individual study room. The questionnaire, adapted from a version suggested in Gameiro Silva *et al* (2004), included questions that helped to characterize each element of the evaluation panel, regarding the anatomic elements and the clothing thermal isolation that they were using, and questions regarding the environment quality, through a continuous voting scale but with a qualitative grade of discomfort. It allows the user to express a value for the intensity in which he/she feels the option that they are classifying. The main characteristics of the evaluation panel are sum up on table I.

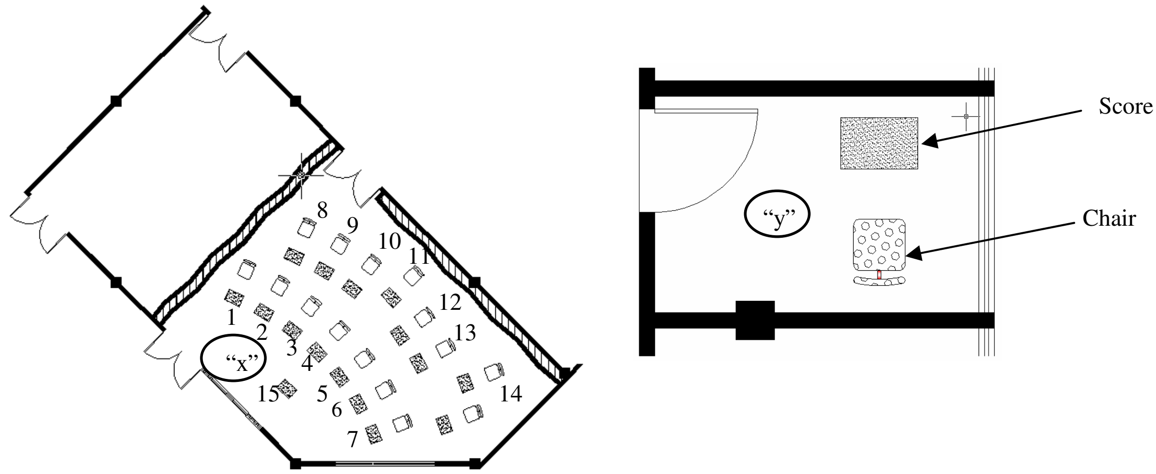

Figure 2 – A: Multimedia Room: "Trombone orchestra" class. B: Individual study room

4 RESULTS

Belo Horizonte is the capital of Minas Gerais state (Brazil), with a population of almost 3 million people. It has an average altitude of 875m and its total area of 331 km^2. Belo Horizonte's climate can be classified as tropical altitude, with yearly average temperature between 16.7°C and 27.1ºC (Assis, Ferreira & Silveira, 2006). The city north region, where the campus is located, is less mountainous and altitude varies between 675m and 850m, with a tendency of low density occupation. Tests were conducted on the 14th March 2007, between 14:00 and 16:00. The university campus' weather station, where the outer weather conditions were registered, is located 1.2 km of the analyzed building. During the testing period, the sky was slightly cloudy, air temperature varied between 26.3ºC and 27.3ºC and relative humidity between 41 and 48%, air velocity was low, about 2.9 m/s W-NW (73.8º); there was no register of rain and the average atmospheric pressure was of 917.4 mBar.

On indoor environments, air temperatures on rooms without air conditioning varied between 25 and 27ºC, while on the multimedia room, that has air conditioning, temperature was of 22ºC during class. The average values measured regarding globe temperatures in both rooms were close to the respective air temperatures; and relative humidity varied between 50% and 70%. Information regarding thermal environment were complemented by the wet bulb temperature and air velocity measurements. Using a computational application, elaborated by Gameiro Silva (2006), the thermal comfort levels PMV and PPD were calculated for each element of the evaluation panel. These levels are defined on ISO 7730 Standard (2005) and were calculated using the thermal environment data (air temperature, globe temperature, wet bulb temperature and air velocity) and the information regarding the metabolism level and the isolation of the clothing used by evaluation panel members. Values determined by the measurements results are compared with the subjective evaluation results obtained through the questionnaire, on fig. 3.

Values obtained, either through the measurements, or through the subjective vote, are within the thermal comfort range ($-0.5 < PMV < 0.5$), thus having an agreement between both methods, although the average subjective vote tends more to the slightly cold than the results obtained through the measurements. Different sizes of amplitudes of variation may be justified by the fact that, on the measurements side, they result of the difference between the clothing and metabolism levels of the elements on the evaluation panel; while as for the vote side, they result of the individual differences of the environment subjective evaluation.

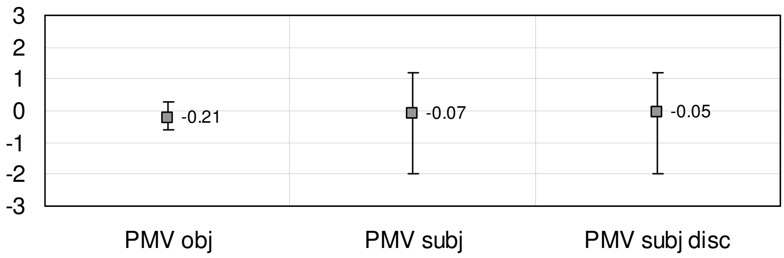

Figure 3 - Results of Subjective Votes (reading of questionnaires in continuous scales)

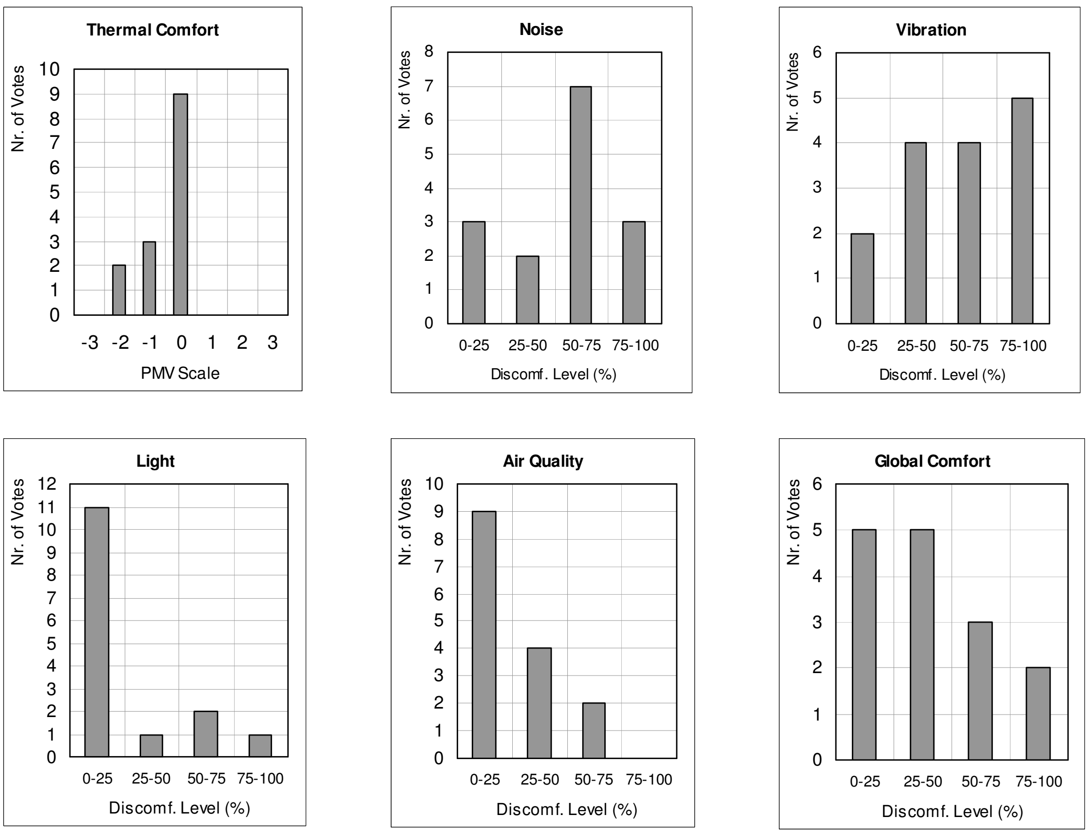

Figure 4 - Results of Subjective Votes (reading of questionnaires in discrete scales)

The indication of the discrete subjective voting presented on the following figure results of the seven discrete scale points grouping, which, as we can see, may lead to some differences regarding the average value concluded. Figure 4 presents graphics with the voting absolute frequency distributions of the evaluation panel elements regarding the environment on the multimedia room. The data was grouped in discrete scales of seven points for the thermal comfort and of four points for the remaining cases. Figure 5 presents the voting average values of the continuous scales and the respective variation range. It was verified that the most important contributions for the global discomfort level of 40% came from noise and vibrations. There is a certain dispersion of the votes from the evaluation panel, but the obtained average values, in the cases that it was possible to establish comparison between votes and indices calculated from measurements, as it happened regarding thermal comfort, conducted to coherent values. In the case of noise, where objective measurements were also performed, values of noise equivalent level, for 5 minutes periods, in the range from 80 to 90 dB(A) justify the discomfort level rated in votes. Regarding the individual room case, where there is no air conditioning, only a subjective vote of one evaluator was obtained. The main discomfort factor is the thermal environment, presenting a calculated PMV, regarding the environmental conditions, of 1.25 and a vote value in the same scale of 1.17. The PPD for this environment would be of 37.5%, which leads to a thermal environment significantly more discomfortable than in the case of mulmedia room.

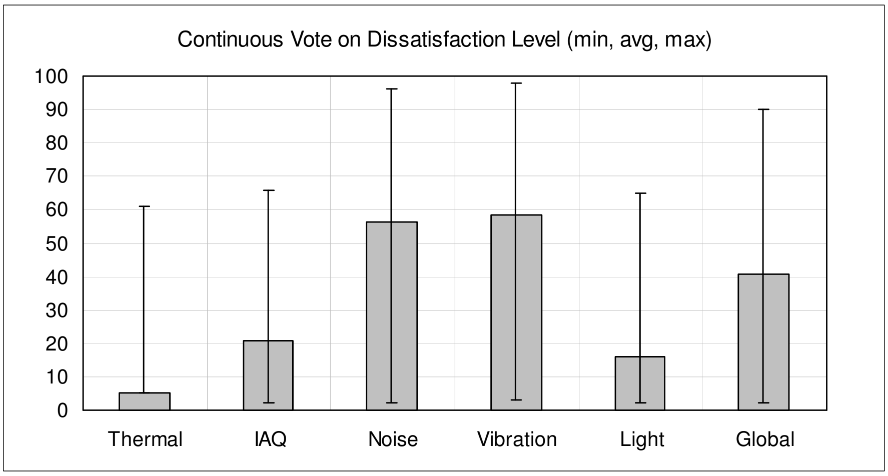

Figure 5 - Results of Subjective Votes (reading of questionnaires in continuous scales)

5 CONCLUSIONS

It was noticed that, regarding the multimedia room environment, the stimuli that contributed more to the discomfort feeling were noise and vibrations (average discomfort level of about 55%); while thermal environment was located very close to the thermal neutrality situation, which corresponds to a PPD rate value (Predicted Percentage of Dissatisfied) very close to the minimum value of 5%, having the remaining stimuli values that are relatively low (15% to 20%). The voting average value of the global sensation of discomfort was of about 40%, which naturally results of the weighting given to the effect of the several discomfort stimuli. The good mark obtained, regarding the thermal environment, for the multimedia room results of the air conditioning work, since the air temperatures were decreased to more comfortable values. The need of air conditioning systems in warmer climates arises as a conclusion from this study.

In the specific case of this school, besides the use of HVAC systems, it is possible to improve indoor environmental quality taking profit of the shadowing provided by vegetation in the left side façades, where most of the lecture rooms are located. Even if it was not specifically considered in the planning directives of the campus, topography, vegetation and distances among buildings contribute favorably to create good indoor environmental conditions in the School of Music. The building is located far from the main streets of the campus and, even in those the allowed circulation speed is low, which contributes positively to the noise environment.

One of the major difficulties faced by an architect while creating a project is by previously understanding the real needs of its users, which sometimes are only discovered after the environment is being used. The conception ergonomics may help the architect to minimize the gap between his ideal representation and the representations of the remaining agents involved in one project (users, contracting, and constructor).

The search for the development of parameters systems that act at a cities scale, of its neighbourhoods and of its citizens, as they try to lead the municipal urban intervention to the real problems of the cities, may be in vain, for each case has its own specificity. Meanwhile, when trying to deal with a complex project, may be it is necessary to have some indicators to guide the architecture's approach for each case he is designing. Ergonomics has methodological tools that are specific for that. School suggested a programme for the architectures to create the project according to the urban conditions of the campus. They wanted a building aesthetically different from the remaining buildings. The final result shows that, on an architecture design, the adopted aesthetic is a major factor to the environmental comfort and of the energy efficiency, thus it should be developed in an effectively compliance with those elements. In order to reach a true sustainable architecture we need to change the basic professional philosophy, of the aesthetic values that require a critical vision regarding technology, politics and economy.

REFERENCES

Assis, E.S.; Ferreira, D.G.; Silveira, S.Q. (2006). Estudo da ventilação urbana na cidade de Belo Horizonte. In: *VI Worshop Brasileiro de Gestão do Processo de Projeto na Construção de Edifícios.* São Paulo: NUTAU.

Azevedo, G.; Rheingantz, P.; Bastos, L. *et al*. (2005). Padrões de infra-estrutura para o espaço físico destinado à educação infantil. In: *COEDI/MEC. Parâmetros básicos de infra-estrutura para instituições de educação infantil* (Documento final), Brasília, Brasil.

Castro, I. S.; Rheingantz, P. A. (2006). Designing and teaching closer to reality: an approach under the ergonomics viewpoint. In: *16TH Congress of The International Ergonomics Association - IEA2006*, 2006, Maastritcht. Meeting Diversity in Ergonomics. Maastritcht : Elsevier Ltd., p. 1207.

Gameiro da Silva, M. C (2004)., Alcobia, C. J. O. P. J. Martinho, N. A. G. Ramos J. M. E .– "Indoor Environment in Vehicles", *International Journal of Vehicle Design,* Vol. 42, Nos. 1/2, pp35-48, 2006

Gameiro da Silva, M. C (2006). Folhas de cálculo para determinação dos índices de conforto térmico PMV e PPD. In: *Congrès méditerranéen des climaticiens. Lyon: Climamed, 2006*. 6p.

Gaudin, T.; Bastos, L. (2007). Alta qualidade ambiental em projetos de edificações escolares. In: *IX Encontro nacional de conforto no ambiente construído*. Ouro Preto: ENCAC, 10p.

Guérin, F. *et al*. (1991). Comprendre le travail pour le transformer: la pratique en ergonomie. Paris: *ANACT*, 233p.

ISO 7730 (2005). Moderate thermal environments-Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.

Martin, C. (2000) Maîtrise d'ouvrage Maîtrise d'ouvre construire um vrai dialogue: la contribution de l'ergonome à la conduite de projet architectural. Toulouse: OCTARÈS, 228p.

Souza *et al*. (1998) Um olhar sobre o Campus: conceitos para a avaliação do ambiente construído. Belo Horizonte: UFMG.

Vilhaça, F. (2001). Espaço Intra-urbano no Brasil. São Paulo: FAPESP, 2ª ed.

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Reducing CO_2. Are industrialised construction systems better?

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ABSTRACT: Greenhouse gas (GHG) emissions attributable to the manufacture of the materials used for a standard dwelling in Spain are equivalent to those for 25 years of its use. This data shows that a significant reduction in emissions from the domestic sectors implies not only reducing the energy demand of the buildings – which is the aim of most environmental action – but also reducing the energy input of materials. Many of the proposals for reducing the environmental impact of buildings use industrialised construction systems because it is believed that they are more energy-efficient. This study compares the emissions from the use and manufacture of a conventional construction system for a dwelling with three specific industrialised construction systems. The results show that the use of industrialised system does not necessarily bring about the overall environmental advantages that are often associated with them; indeed, they can even be counter-productive.

1 INTRODUCTION

Technological process has led to changes in how buildings are constructed. Some conventional building materials and systems have been replaced by industrialised materials and systems with the aim of attaining new levels of quality and features. Nevertheless, this transformation has also involved an increase in the amount of energy required for the manufacturing process.

Table 1. Energy required to produce construction materials (INSTITUT CERDÀ, 1999).

Aggregates	0.1	MJ/kg	Steel	43	MJ/kg
Bricks	2.8	MJ/kg	Polyurethane	70	MJ/kg
Sawn timber	3	MJ/kg	Polyethylene	75	MJ/kg
Plaster	3.3	MJ/kg	PVC	80	MJ/kg
Plywood	5	MJ/kg	Copper	90	MJ/kg
Portland cement	7.2	MJ/kg	Paint (enamel)	100	MJ/kg
Asphalt	10	MJ/kg	Expanded polystyrene	100	MJ/kg
Chipboard	14	MJ/kg	Neoprene	120	MJ/kg
Glass	19	MJ/kg	Aluminium	215	MJ/kg
Plastic paint	20	MJ/kg			

As shown in Table 1, traditional materials, i.e. stone and wood, require 5 MJ for the manufacture of each kilogram of material. With the industrial revolution, new materials such as cement and steel came into use, and the energy required to manufacture them increased to 50 MJ/kg. The most recent technological advances have led to the generalised use of plastics and metals, which require up to 215 MJ/kg.

The high energy cost of these industrialised materials is reduced if we consider the overall energy of the unit of service, since the amount of material used to cover a given need is generally less than of the amount of traditional materials that was necessary.

Thus, we find examples of 'bioclimatic' or 'ecological' architecture designed by world-renowned architects using industrialised systems to reduce the energy cost of buildings during use, without taking into account the environmental cost of their construction.

In the case set out below, we calculate the amount of energy and CO_2 emissions attributable to the construction and use of a particular building made with various construction systems. We compare the energy used for a conventional construction system with that used for three industrialised construction systems. One is a lightweight industrialised system with a steel structure and lightweight façades, and the other two are light-heavyweight and heavyweight industrialised systems using prefabricated reinforced concrete.

2 CASE STUDY

2.1 *Background*

The original aim of this study was to show that a given lightweight industrialised construction system was more sustainable than the conventional construction systems used in Catalonia. The original study was commissioned to Societat Orgànica and a team from UPC. The main results were published in the proceedings of the World Renewable Congress IX (PAGÈS, 2006).

In the study shown below, we have increased the number of construction systems analysed. In this case, apart from the lightweight industrialised construction system and the conventional construction system, a heavyweight industrialised construction system and a light-heavyweight industrialised construction system have been added to the comparison.

2.2 *Description of the construction systems analysed*

This study compares four different construction systems used for housing in terms of energy and CO_2 emissions. These are as follows:

2.2.1 *Conventional construction system (3069 kg/m^2)*

This is the system most commonly used for housing construction in Catalonia in recent years. The buildings have brick walls – which are the main structure of the building – and a concrete roof, with two-layer exterior walls, inverted roofing and plastered brick interior partitions.

2.2.2 *Lightweight industrialised construction system (1196 kg/m^2)*

This is a lightweight system built with a steel structure. The façades are made from interior plasterboard panels, mineral wool, plant fibre, cement panels, a ventilated chamber and ceramic cladding. The roof and the floor, which is raised above natural ground level, are also lightweight. The interior walls are made from plasterboard with mineral wool insulation. All assembly is dry, including both structure and skin.

2.2.3 *Light-heavyweight industrialised construction system (1752 kg/m^2)*

This is a light-heavyweight industrialised construction system built with a prefabricated reinforced concrete structure. The exterior walls are made from interior plasterboard panels, 8 cm of reinforced concrete, mineral wool and steel sheet cladding. The roof and the floor, which is raised above natural ground level, have a reinforced concrete structure. Thermal insulation is applied to the exterior.

2.2.4 *Heavyweight industrialised construction system (3602 kg/m^2)*

This system has the same characteristics as the light-heavyweight industrialised construction system. The only two relevant differences are that the floor is not raised above natural ground level and that insulation (expanded polystyrene) is not applied to the exterior but rather between two layers of reinforced concrete.

2.3 *Analysed building*

To compare the four construction systems, we considered a detached single-family building with a floor area of 84 m^2. The shape of the building and the position and surface area of the windows were the same in all cases.

The study was based on a Mediterranean climate, specifically that of Barcelona, and on the building regulations and conventional construction systems in use there. The thermal regulations currently in force in Barcelona are the Catalan Autonomous Government's Eco-efficiency Decree and the Spanish Technical Building Code. In order to make an equal comparison, the minimum insulation required to meet these thermal regulations was used for all four systems.

To calculate the energy consumption and the CO_2 emissions associated with the use of the building, we assumed constant occupancy and applied the performance of air conditioning systems to the demand values. Gas-fired radiators (80% efficiency) were used for heating and heat pumps (200% efficiency) for cooling.

Another comparison was then made with a variation in the insulation. Five centimetres of insulation were added to the exterior walls, roof and floor in order to improve the performance of the building during its use.

2.4 *Tools*

To quantify the energy demand and CO_2 associated with the use and construction of each system, the following computer programs were used:

2.4.1 *TCQ 2000 by ITeC*

TCQ 2000 has an Environmental Management Module with UPC-validated data that can calculate the CO_2 emissions and energy used in the construction of a specific building on the basis of its component materials, as quantified in ITeC's price database for 2006, and provides environmental particulars (energy and emissions) for the building.

2.4.2 *Lider, version 1.0 (27 March 2007)*

Lider (limitation of energy demand) is a program associated with the Spanish Technical Building Code approved in March 2006. The program simulates the demand, taking into account all areas of the building. The environmental datum obtained in this way is the yearly energy demand for the particular building.

3 RESULTS

There are two sets of results. Section 3.1 compares the results of the four construction systems with the minimum insulation required to meet the thermal regulations. Section 3.2 compares the results of the same four construction systems with five extra centimetres of thermal insulation in the exterior walls, roof and floor of the building.

3.1 *Comparison of construction systems with minimum insulation*

3.1.1 *Construction comparison*

Figure 1 shows the construction impact measured as CO_2 (kg of CO_2 emissions/built-up m^2) for the four buildings studied.

The most efficient construction system is the conventional one, with 703 kg CO_2/m^2 (or 1925 kwh/m^2 in terms of energy). The light-heavyweight system has 10% more CO_2 emissions than the conventional system whereas the heavyweight system has 21% more. This difference between the two reinforced concrete construction systems is due to the larger quantity of reinforced material in the heavyweight system, since the walls are double.

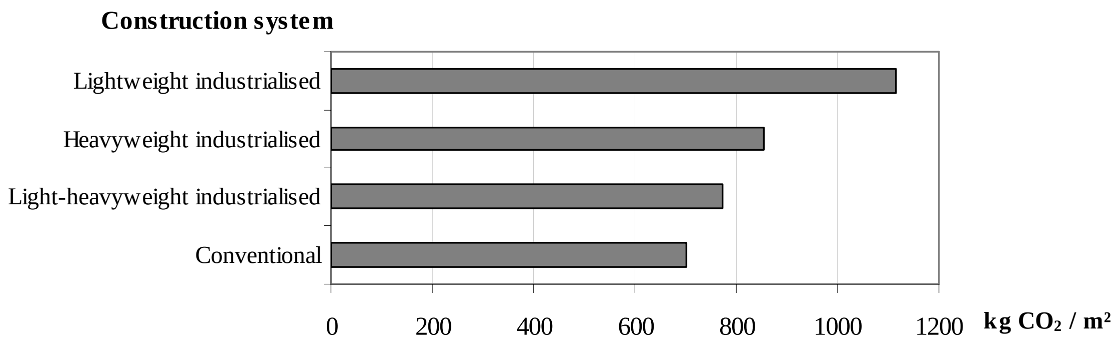

Figure 1. CO_2 emissions due to the construction process.

Although the lightweight industrialised building is 2.5 times lighter than the conventional building, it involves 60% more CO_2 emissions. This impact is caused mainly by the steel structure, which accounts for 60% of the total impact of the building but only 15% of the total weight.

In order to reduce the impact caused by the steel in the lightweight building, we can use recycled materials that have less environmental impact. In this case, the steel could be replaced by the same material with a recycled content of 100%. The 35 MJ of energy required to produce one kilogram of new steel can thus be reduced to 25 MJ. By recycling all the steel used in this building, we reduce the construction impact by 20%. This is a significant reduction, but it is not sufficient to reach the values of the other construction systems.

The environmental advantage of this lightweight industrialised construction system is the ease of assembly and demolition. That is, once a building's useful life is finished, its components can be put to other uses. Although this is an important advantage, we must admit that it is based on a hypothesis of future use rather than on impact reduction from the outset.

In the comparisons, we therefore did not consider that the materials of the lightweight industrial construction system could be recycled or reused at the end of their useful life.

3.1.2 *Use comparison*

Figure 2 shows the CO_2 emission impact during use. There are no significant differences between the emissions of the four buildings. The largest difference, of 14%, is between the lightweight industrialised construction system, which is the least efficient, and the heavyweight industrialised system, which is the most efficient.

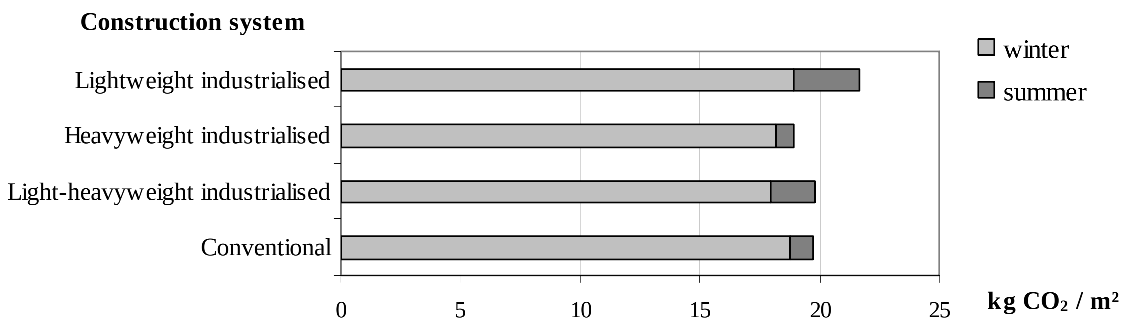

Figure 2. CO_2 emissions due to building use.

The systems have similar energy performances because they meet the minimum requirements of the thermal regulations. However, they do not have exactly the same energy demand because the thermal transmission coefficient (shown in Table 2) and mass of each construction system are different.

Table 2. Thermal transmission coefficients (W/m^{2}K).

Construction system	Wall	Roof	Floor
Lightweight industrialised	0.34	0.37	0.51
Heavyweight industrialised	0.68	0.52	0.59
Light-heavyweight industrialised	0.42	0.47	0.56
Conventional	0.70	0.48	0.59

With respect to the total, the summer emissions are lower in the heavyweight and conventional buildings than in the light-heavyweight and lightweight buildings. The summer use of the heavyweight building accounts for just 3.6% of its overall use-related emissions, whereas in the lightweight building it accounts for 11.7%. These two buildings show the greatest difference in emissions in the summer: the heavyweight system is 3.6 times more efficient than the lightweight construction system. This is due to the mass of the heavyweight buildings, which provides thermal inertia and allows a phase lag between indoor and outdoor temperatures.

3.1.3 *Overall comparison*

Taking into account both construction and use (considering a useful life of 60 years), we can make several comparisons. Figure 3 shows the proportion of use-related to construction-related CO_2 emissions. Construction accounts for between 38 and 44% of the building's total emissions.

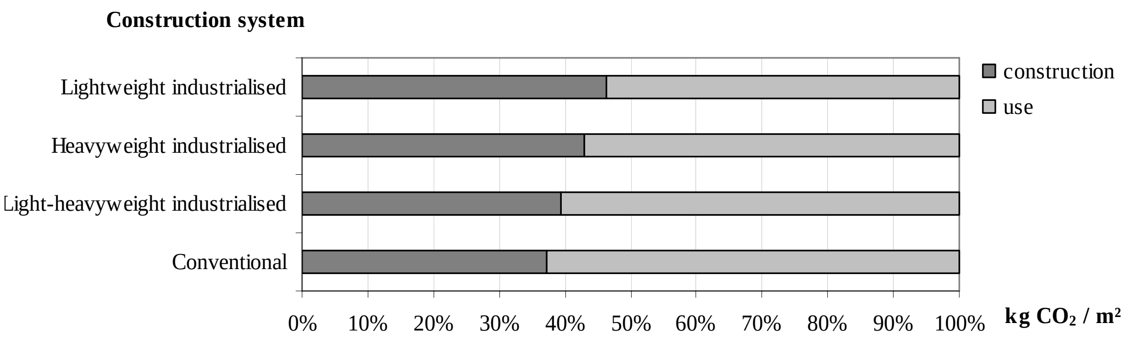

Figure 3. Proportion of emission sources.

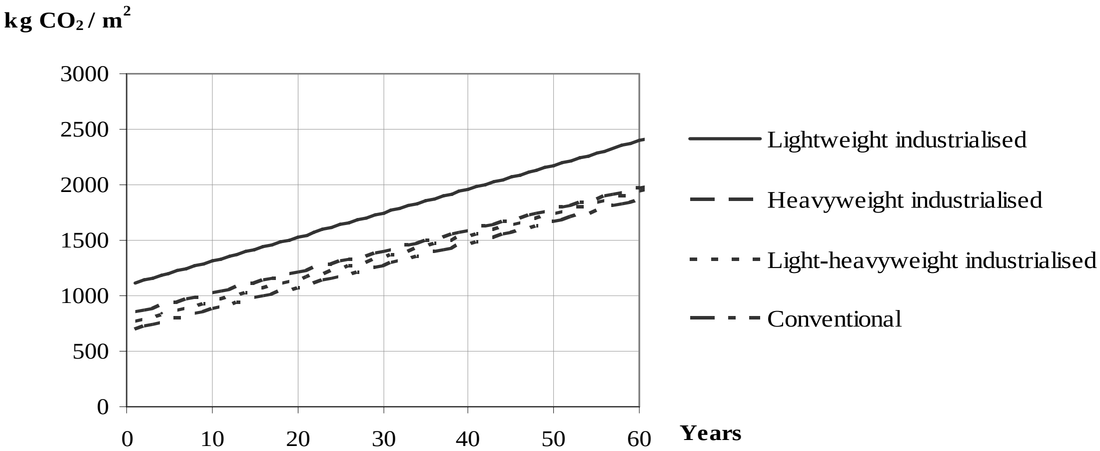

Figure 4. Evolution of the quantity of emissions.

Figure 4 shows the aggregate impact over 60 years for the four cases studied. The lightweight industrialised construction system, which is the most inefficient during use and construction, shows a great difference from the other three systems in terms of CO_2. The other three systems have similar emissions at the end of their useful life, but the most efficient is the conventional construction system. The difference between the worst (lightweight) and the best (conventional) is over 28% with respect to the last one.

3.2 *Comparison of construction systems with an extra 5 cm of insulation*

3.2.1 *Construction comparison*

Adding 5 cm of insulation to the walls, roof and floor involves increasing the emissions and energy required to build the house. For the various construction systems, the increase in CO_2 emissions ranges from 1 to 11% in comparison with the minimum insulation case. The actual increase depends on the kind of insulation that each construction system uses; for example, the lightweight industrialised system uses mineral wool, which has a much lower impact than the expanded polystyrene used in the heavyweight industrialised system.

Although CO_2 emissions increase differently with each system, the comparison of the various systems remains nearly unchanged, as shown in Figure 5.

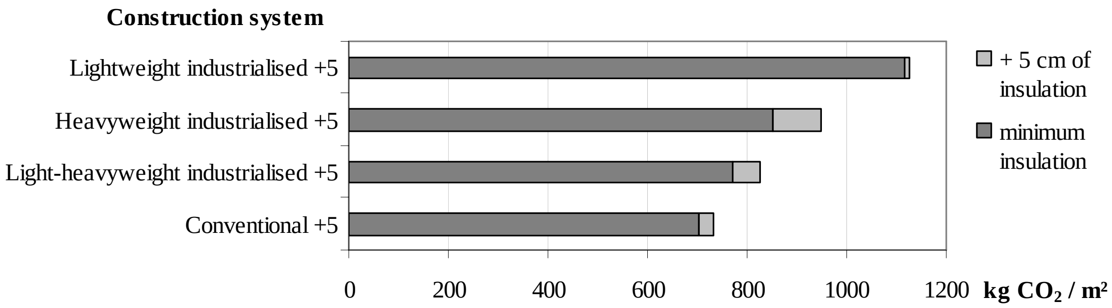

Figure 5. CO_2 emissions due to the construction process.

3.2.2 *Use comparison*

With an extra 5 cm of insulation, use-related CO_2 emissions decrease considerably for all four construction systems. The lightweight industrialised system improves its performance by 15%, the heavyweight and light-heavyweight industrialised systems by 23%, and the conventional system, which shows the greatest improvement, by 25%.

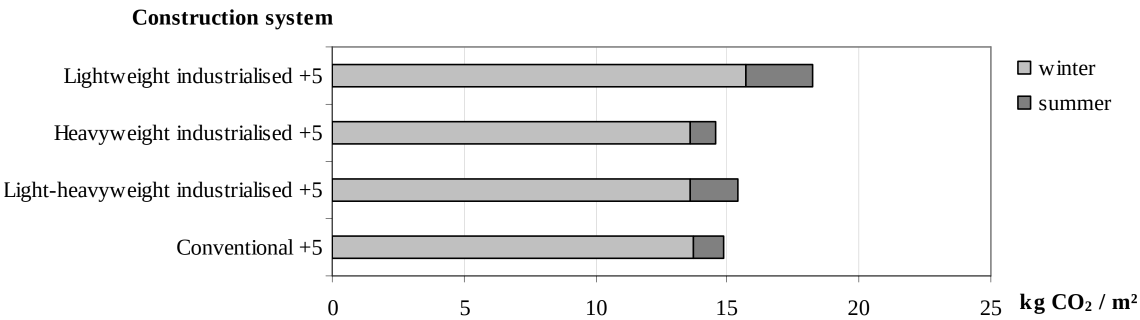

Figure 6. CO_2 emissions due to building use.

Figure 6 shows that the lightweight industrialised building has the highest CO_2 impact during use. It is 25% more inefficient than the heavyweight industrialised system, which is the most efficient. This difference was only 14% without the extra insulation, as explained in Section 3.1.2. This is because the performance of the industrialised construction improved much less than the performance of the other systems.

In Section 3.1.2 above, the industrialised system has the lowest thermal transmission coefficient with the minimum amount of insulation allowed by law. Table 3 shows that it also has the lowest coefficient in this comparison, but all of the analysed systems have similar values because it is more difficult to improve a low thermal transmission coefficient than a high one.

Table 3. Thermal transmission coefficients (W/m^2K)

Construction system	Wall	Roof	Floor
Lightweight industrialised	0.20	0.22	0.28
Heavyweight industrialised	0.36	0.31	0.33
Light-heavyweight industrialised	0.25	0.28	0.31
Conventional	0.33	0.28	0.23

3.2.3 *Overall comparison*

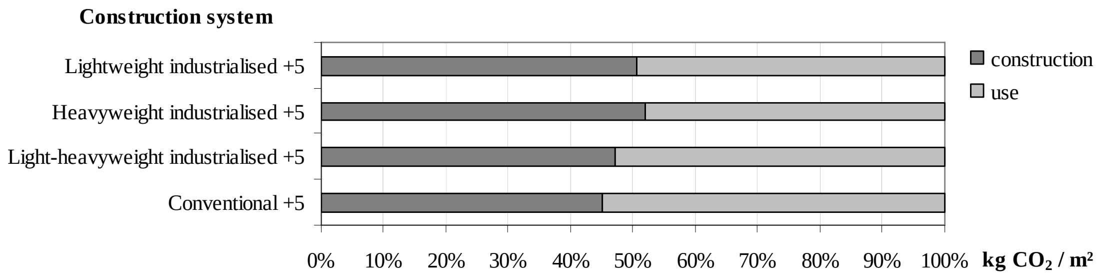

Figure 7. Proportion of emission sources.

Figure 7 shows that construction-related emissions account for between 45 and 52% of the building’s total emissions, taking into account both construction and use. This percentage is higher than in the previous comparison (Section 3.1.3) because the emissions during use decrease considerably.

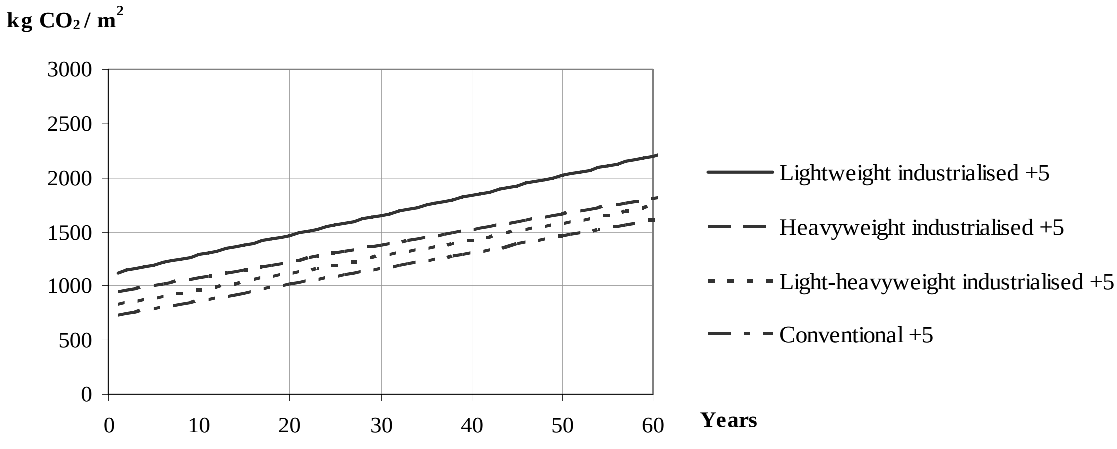

Figure 8. Evolution of the quantity of emissions

Figure 8 shows aggregate impact over 60 years. As in the comparison with the minimum insulation (3.1.3), the conventional building is the most efficient. The light-heavyweight building produces 8% more emissions, the heavyweight building 12% more and the lightweight building 37% more.

4 CONCLUSIONS

In the region studied, of the total CO_2 emissions produced by a building during its useful life (60 years), between 38 and 52% is attributable to its construction. Therefore, we cannot expect to reduce the overall environmental impact of a building by applying only demand-reduction strategies without taking into account the increased impact of such strategies on the construction process.

The case study shows a priori that an industrialised construction system is no better than the conventional construction system in terms of energy savings and the reduction of CO_2 emissions. However, we must distinguish between the lightweight and heavyweight industrialised construction systems.

The impact of manufacturing the materials for a building with a lightweight industrialised system is always greater than the impact of manufacturing conventional or heavyweight materials for the same building, even if the main industrialised materials are recycled. On the other hand, the use-related energy required for a building built with the lightweight industrialised construction system is always greater than that required for the other systems. Even if we improve the performance of the building built with a lightweight industrialised system by adding 5 cm of insulation without optimising the other systems, by the end of its useful life, the industrialised system produces more emissions than the others.

The light-heavyweight and heavyweight industrialised systems and the conventional system have very similar impacts during the use of the building. However, considering construction-related emissions, the two industrialised systems produce a much greater amount of emissions than the conventional system. This implies that the conventional building is the most efficient.

This study demonstrates that the conventional building is still the best, taking into account the emissions associated with both construction and use. It is the best when the building meets the minimum legal requirements. It is also the best when the building's performance is improved by adding an extra layer of insulation. In absolute terms, it is the system that can save the most energy and CO_2 by adding insulation.

The overall performance of a building might not be improved by changing to an industrialised construction system. The sustainability of a building will be improved, however, by adapting its design to the climate. In a Mediterranean climate, this involves adding insulation and mass.

REFERENCES

Institut Cerdà, 1999. *Guía de la Edificación Sostenible. Calidad Energética y Medioambiental en la Edificación.* Madrid: Institut Cerdà, Ministerio de Fomento and IDAE.

Pagès, A., Cuchí, A., López, F. and Sagrera, A. 2006. The industrialised construction system versus the conventional construction system: possibilities for reducing CO_2 emissions. A case study. In *World Renewable Energy Congress IX – Full Proceedings.* WREC, 2006: pp. 1-6.

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Integration of sustainability solutions in sanitary installations: the example of the AveiroDOMUS "House of the Future"

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ABSTRACT: The University of Aveiro, in association with a group of interested companies, created an association called AveiroDOMUS, the main purpose of which is to design and build a "House of the Future". This house is developed under sustainable construction principles resorting to state-of-the-art and environmentally friendly technologies.

One of the major goals of the project is the optimization of the hydrologic cycle in the House, under sustainability principles such as water recycling, the use of rainwater, the incorporation of low flow fixtures and the use salt water, which is abundant in the area where the house is to be built – the Aveiro Salt Lagoon. This paper discusses the scheme of the water cycle and describes the solutions proposed for the several sanitary installations of this "House of the Future" in detail, pointing out, in each one of the steps, the measures that have been adopted towards the sustainability principles.

1 INTRODUCTION

The Portuguese city of Aveiro is 250 km from Lisbon, the capital, and 10 km from the Atlantic coast. It is surrounded by a saltwater lagoon system that occupies 110 km^2 of the River Vouga estuary (figure 1 and figure 2). The region of Aveiro is on the northern part of Portugal's coast and is regarded as a highly dynamic economic zone. A considerable number of industrial sectors are base there, involving all kinds of business activity, especially in the construction sector.

Figure 1. Location of Aveiro

The University of Aveiro was founded in 1973 and is now considered one of the most innovative and dynamic in Portugal. It is a university of international repute known for its academic excellence, research, innovation, state-of-the-art technology and cultural input. It is the only

Portuguese university that is a member of the ECICU – European Consortium of Innovative Universities, an organisation which has, over the years, been involved in countless activities in the spheres of Education, Research, Land use planning and Institutional development.

The House of the Future (figure 3) project is an interdisciplinary project involving 12 companies from the Aveiro region and various university departments. The House of the Future cooperation network that is known as AveiroDOMUS was created in 1999, with the University of Aveiro as its chief backer.

Figure 2. Aveiro Ria – Lagoon Área

2 AVEIRO'S HOUSE OF THE FUTURE PROJECT

The strategic goals of the House of the Future project are to develop new conceptions in the sphere of housing and to create conditions to build a potential futuristic house in the short term.

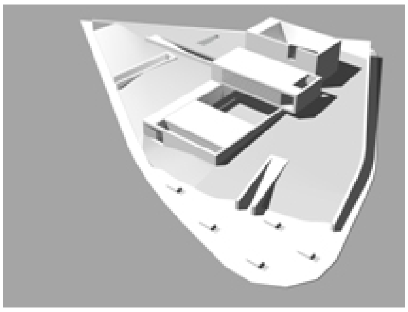

Figure 3. AveiroDOMUS House of the Future

The house must obviously be of an advanced design, but the main objective is to build it in accordance with sustainable building standards, ensuring proper interaction with local ecosystems and a good interior environment (air quality, absence of noise, comfortable temperature and humidity, light, etc.). Another pertinent aim is to reduce consumption of essential resources through the appropriate choice of materials and use of renewable energies and by optimising the water cycle.

The AveiroDOMUS House of the Future will be a permanent research and development laboratory, open to both industry and the public. In fact, one part of the house will be open to visitors, another part will be inhabited and a third part will be under study and evolving. These areas will be rotated from time to time.

3 THE WATER CYCLE IN THE HOUSE OF THE FUTURE PROJECT

The efficient use of water is an environmental priority today, and this is the main goal in terms of optimising the water cycle in the House of the Future.

It is general knowledge that water use in the home has different quality requirements, and this creates the chance to make use of different sources of supply, depending on the quality needed for the specific use. Rainwater can be used for flushing toilets, in washing machines, for cleaning the floor, washing cars, watering the garden, provided that it has been adequately pre-treated. A rainwater collection system can save 50% of treated water (from the mains system), with no loss of comfort or hygiene, within the consumption profile.

A system that includes the partial recycling of domestic wastewater has been planned for the House of the Future, with the aim of cutting the use of mains water to a minimum. At the same time, low-consumption devices will be used, linked to the use of alternative sources (rainwater). The House of the Future also has contemplated the use of saltwater and groundwater, and, since the land occupied by the House is very close to the area of influence of the Aveiro Ria's town canals, the groundwater is quite likely to have some salinity (figure 4).

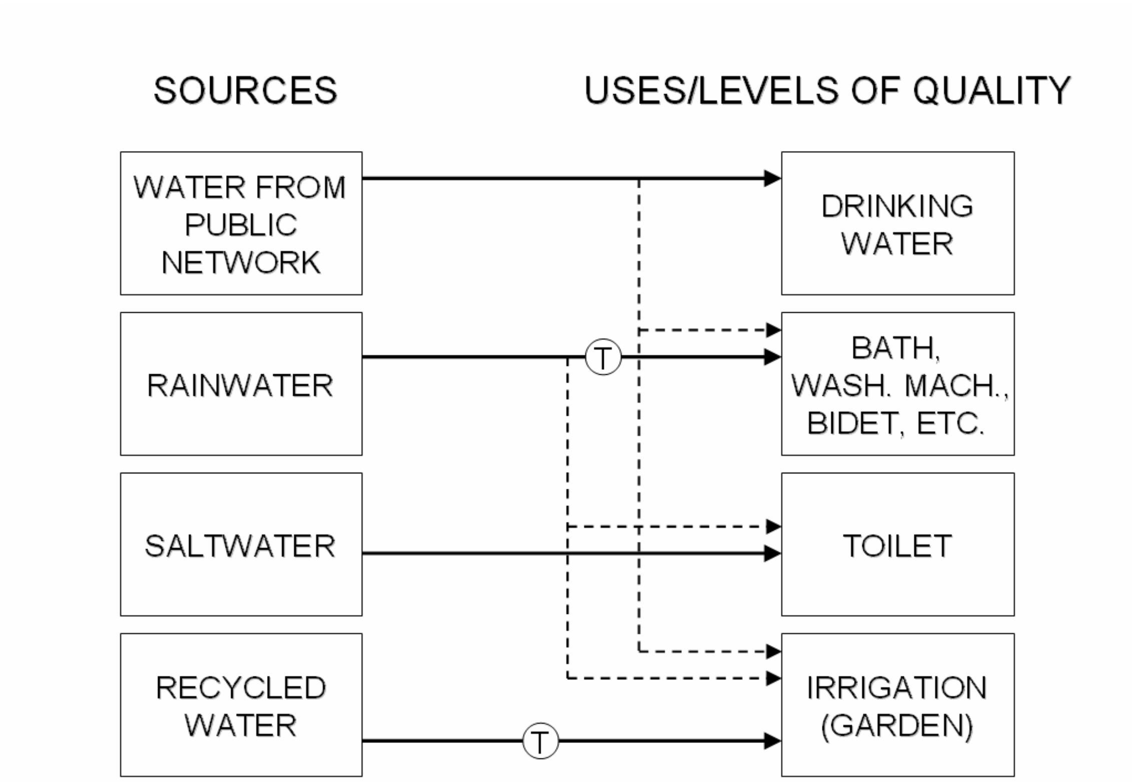

Figure 4. Water use scheme

The establishment of a non-desalinated saltwater supply line is one solution that could be a useful alternative when drinking water is in short supply, in coastal regions (like Aveiro), for purposes that do not need high quality water (toilet cisterns, for instance). The use of saltwater, though it may give rise to problems in terms of treatment, is currently used in many parts of the world, including Hong Kong etc. It can help to solve many drinking water shortage problems in those coastal regions and in Madeira and the Azores.

In terms of cutting consumption, the following were among solutions considered for the House of the Future: use of small volume cisterns; low-flow fixtures; timers and other automatic control devices; air emulsifiers; waterless (i.e. chemical) urinals, and low-consumption washing machines. Within this consumption-cutting goal, special attention will be given to cisterns, which can be waste a considerable amount of water (over 30% of total consumption in the residential sector, according to some authors). In the case of urinals, the use of chemical ones (with a liquid sealant) that do not consume any water is envisaged.

In terms of wastewater, several treatment systems will be looked at in this project, bearing in mind the proposed water cycle. The ultimate aim for non-reused water will be to achieve a quality that will allow the effluent resulting from the treatment process to used on the garden or to ensure a level of quality so that it can be discharged into the receiving environment.

There will be several steps in the treatment system, each with a specific purpose, including the removal of solids and other insoluble matter, the removal of biodegradable matter and the removal of chemical and microbiological contaminants. The reuse of solid material (sludge) produced in the treatment process will also be examined.

4 AVEIRODOMUS HOUSE OF THE FUTURE: SUB-PROJECTS RELATED TO THE WATER CYCLE

The water cycle in the House of the Future (figure 5) project will be studied under two Subprojects: Indoor Water and Specific Rooms. The Specific Rooms Water Cycle sub-project starts at the point of entry of water into the bathrooms and ends at the discharge point of the wastewater produced there, and is a transit point in the water cycle of this futuristic house, which is also linked to architecture.

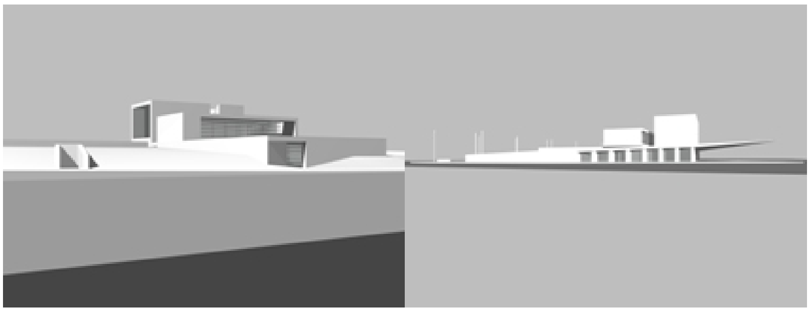

Figure 5. AveiroDOMUS House of the Future

This work lays particular emphasis on the use of water from alternative sources and the possibilities of reusing it, along with fixtures, treatment plants, sanitary equipment, use devices and accessories that help to cut water consumption, while maintaining comfort and satisfaction for the house's occupants.

5 TYPES OF BATHROOM

The characteristics envisaged for the House of the Future's bathrooms will chime with the basic concepts of this futuristic house, which aim to endow the AveiroDOMUS's House of the Future (figure 6) with mobility, adaptability and ability to change.

Different features will typify the bathrooms for the House of the Future, and these are related to the applicability of new products in different solutions under development within the Subprojects.

In one case, the bathroom's cistern will be supplied by a salt or brackish water line, and will have system that separates and collects solid and liquid waste matter. Both types of waste will be treated, and the possibility of the end products yielded by the composting of the solid phase being reused on the garden is being studied.

A single-unit bathroom that can be moved around inside the house is also planned. It will have runners so that the sanitary fixtures and fittings can be easily rearranged inside it. This bathroom will have independent water storage and wastewater collection systems.

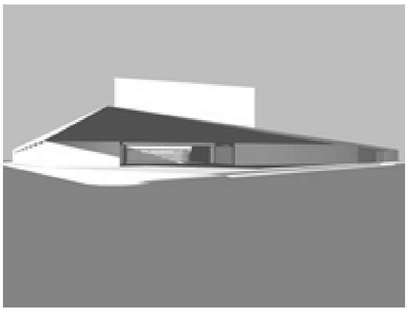

Figure 6. AveiroDOMUS House of the Future

In relation to the choice of sanitary fixtures, there is a vast range of options from a panoply of solutions with every kind of aesthetic theme. The criterion for choice should be based on minimising water consumption (even though it should still be possible to regulate consumption and pressure requirements of the fixtures by fitting accessories).

Besides meeting the aesthetic requirements of bathrooms, aspects related to comfort and hygiene have not been ignored, and it was imperative to fit accessories with devices that meant they could not be touched, especially in bathrooms used by the general public. It is intended that in these bathrooms, from the time the visitor enters until they leave, it will be impossible to touch any kind of object (door, soap dispenser, taps, automatic rubbish bins, etc.).

6 CONCLUSIONS

Besides developing various solutions for the future that are linked to the concept of increasing ease and flexibility of use, the Indoor Water and Specific Rooms Sub-projects of the AveiroDomus House of the Future's Water Cycle will provide an opportunity to study the possibility of optimising the water cycle in homes. It will also help to gear all the technical requirements to the needs of the occupants of the futuristic house, improving the comfort and adaptability of bathrooms.

Studies currently underway are showing the usefulness and feasibility of incorporating devices to cut consumption, adopting measures for reusing water and making use of other sources of water (rainwater, non-desalinated saltwater, groundwater, etc.).

REFERENCES

Oliveira, A., Silva-Afonso, A., Costa, V., Figueiredo, J., Coelho, C.,Figueira, E., Pereira, S. 2006. Optimization of The Water Cycle in the "House of the Future" of The University of Aveiro; *International conference RSC 06 - Rethinking Sustainable Construction 2006. Next Generation of Green Building*. Sarasota.

Oliveira, A., Silva-Afonso, A., Robalo, P, Gomez, M., Caniço A., Almeida, J., Alvim, J., Claro, S. Castro, A. 2006. *Sub-projecto de Divisões Especificas de WC*. Aveiro: AveiroDOMUS.

Silva-Afonso, A. 2001. *Contributos para o dimensionamento de redes de águas em edifícios especiais. Aplicação de modelos matemáticos*. Porto: Faculdade de Engenharia da Universidade do Porto.

Certifying a sustainable reconstruction of vernacular architecture in Peneda-Gerês National Park

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ABSTRACT: In this paper we apply an environmental certification method to the rehabilitation of buildings in environmental sensitive areas, namely in the only National Park located in Portugal. A case study will be presented as a means of verifying the method. The certification of green buildings is one of many ways of reducing the environmental impact of buildings. In several countries there is already one or more of these methods available. In Portugal a method called LiderA has just been made public. Our aim is to apply this method and test it as a tool for architects to environmentally assess the reconstruction of the vernacular architecture located in the National Park of Peneda Gerês (PNPG), and ultimately to certify those retrofitted buildings. The house in Serra da Peneda, will be turned into an ecology field station (ECP) whose certification evaluation will help us establish the feasibility and adequacy of some requirements

1 INTRODUCTION

Portugal is a country with many protected natural areas and tourism. Almost 20% of the country area is under protection and nature tourism is growing at a rate of 7% per year. These protected areas are very attractive for both national and international tourists, which can have a strong impact on its conservation. A national strategy based on sustainable tourism is required in order to preserve these areas. Since tourism depends on the construction industry, the environmental assessment of construction in these areas could prevent significant impacts. Like in other countries, the building certification has been a way of encouraging the construction industry to become more environmental friendly and several systems are now widely accepted in the UK (BREEAM), USA (LEED), Canada (GB Tool) and Japan (CASBEE).

2 THE EXISTING CERTIFICATION METHODS IN PORTUGAL

The energy certification of buildings is recently available in Portugal thru the approval of the Decree of Law 78/2006 on April 4th 2007. Furthermore the environmental and voluntary certification of buildings will be possible during 2007 thru the LiderA method developed in IST (Manuel Pinheiro, 2006). This method consists of an adaptation of several methods developed in other countries and by different teams to the Portuguese construction and environmental scenario.

The present paper uses this method to verify the possible certification of a restored house in Minho. Although there are some new buildings under certification in Portugal, this one is a particular case that consists of not only retrofitting a building but also doing it in a protected natural area.

3 THE PENEDA GERÊS PARK AND ITS CERTIFICATION BY EUROPARC

The Peneda-Gerês natural park is the only national park in Portugal and has around 9000 inhabitants and five counties. The park is visited by thousands of people each year and the protection of species and landscape, as well as the environmental education, are priorities for its authorities. The Park aims to provide a special tourism, eventually certified in all its aspects: certified landscape, environmental education and certified buildings:

- The landscape is presently certified by the international Europarc Federation (European charter for sustainable tourism in protected areas) together with its adjacent Galician park partner, the Baixa de Limia -Serra do Xurés Natural Park. This mark is valid for 5 years and it aims to promote tourism in areas that are both nature and landscape friendly, meet the visitors and the local population and contribute to the economic development of the region.
- The education is to be provided in 5 new thematic buildings to be built in each Park county border. So far the Park built two of those buildings called «Portas» like in S. João do Campo and Lamas de Mouro, and three more «Portas» are being designed (Paradela, Lindoso and Mezio) .
- The certified lodging can be the next step thru the retrofitting of more than 50 granite houses, fifteen of them for renting (shelters, rustic houses), since it is not required by the «Europarc» seal. These buildings can contribute for an environmental education as well.

4 CERTIFYING BUILDINGS IN A PROTECTED NATURAL AREA

The Park of Gerês is a mountainous area with several clusters of old and small granite houses. In the past shepherds used to move their cattle from the upper lands to the lowlands during the snowy Winters and built houses in those places called Inverneiras (winter villages). During the Summer the cattle would move up in order to find better grasslands in the so called Brandas (summer villages). Most winter villages are now abandoned, and some houses are in ruins or for sale. Retrofitting can be a solution since most tourists look for historic lodging and for nature proximity. In the summer campgrounds suit groups of children but during other seasons, schools tend to rent houses that still cannot comply with thermal requirements especially during wintertime. The houses made of granite work fine in the summer due to the thermal inertia.

Retrofitting more houses could prevent new construction and could contribute for restoring the transhumance villages that consist of a unique historic patrimony that will soon disappear. A reconstruction based on little environmental impact could help preserve the local nature and certification could be a good marketing tool to attract nature oriented tourists. The certification could either be the energy certification or the broader environmental certification by LiderA.

The application of the LiderA national method to the case study will tell us if the method should be adapted to a more regional and specific case like the retrofitting of vernacular architecture in the Park.

5 THE CASE STUDY

5.1 *The existing house*

The house being presented is a granite house built in the 30`s which is detached although it is part of a cluster of 3 more houses located in an Inverneira called Podre. It is facing the east side of Castro valley and the lot spreads over 1000m2 down the slope. Its location provides a privileged view over the valley and the plateau of Castro Laboreiro. The latitude is 42ºN and the longitude is 8ºW. Its climate is rigorous in the winter, with mild summer temperatures. The precipitation is high and in the summer the forest fires are frequent. The house is close to an oak forest and its west side is shaded most of the day. It used to have 2 stories, the upper floor for housing, and the lower floor for animals. These animals provided a heat source for the living upper space. The construction materials used were blocks of granite from a rock nearby, oak wood harvested from the forest nearby and roof tile still in good condition.

Figure 1. The existing house.

5.2 *The project*

The house was converted into an Ecology field station, called ECP (Estação de Campo da Peneda) for ecologists to do field work, experiments, and attend seminars. In order to adapt the space from a housing space to a mix school-lab-living space, the building was raised 1meter. The new roof provides a south orientation for solar collectors and photovoltaic panels. The new building has a two-storey-high working space with a mezzanine for 6 beds, a small lab, two bathrooms, two bedrooms, a living room and a small kitchen. There is also a shed for the heating equipment.

The insulation of the shell was critical to avoid damp and increase thermal comfort. The glazing area increased over 75% and the building increased its exposed thermal mass in 17% (27m2). The upper floors have now a floor vs. glazing area ratio of 23% and the lower floor of 10%. The cross ventilation was provided in almost every space. The heating system is based on solar collectors and biomass. The house construction was finished in August 2007. The landspacing is still ongoing.

The construction materials were chosen according to their volume and environmental impact. The majority was recycled, a significant percentage are local materials (produced in the district of Braga), and the certified materials are both national and international.

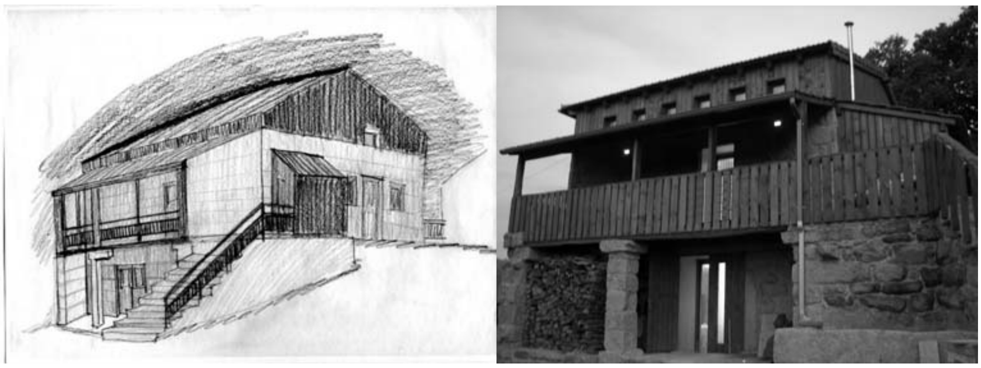

Figure 2. ECP (Peneda Field Station): the project (left) and the finished building (right).

5.3 *The LiderA certification*

The LiderA system is a voluntary system for recognition of sustainable buildings. It is based on 6 parameters with different weights: Local and integration (18%); Resources (35%), environmental Loads (15%); Indoor Environment (20%); Durability and Accessibility (5%); Environmental Management and Innovation (9%).

These parameters are divided in sub-parameters and criteria illustrated in Table 1.

Table 1. The LiderA criteria and weights (Pinheiro, 2006)

Parameters	Sub-parameters	Wi	R	criteria	C#
Site and integration	Soil	7	S	Site and valorization	C1
				Occupied area	C2
				Ecological functions of soil	C3
	Natural ecosystems	5	S	Natural areas	C4
				Ecological valorization	C5
	Landscape	1	S	Local integration	C6
	Amenities	1		Local amenities valorization	C7
	Mobility	4		Low impact mobility	C8
				Public transport access	C9
Resources	Energy	18	S	Passive energy performance	C10
				Total electricity consumption	C11
				Renewable resources based energy	C12
				Consumption of other energy sources	C13
				Consumption of other renewable sources	C14
				Equipment efficiency	C15
	Water	10	S	Consumption of potable water (indoors)	C16
				Consumption of water in common spaces and outdoors	C17
				Control of consumption and loses	C18
				Use of rainwater	C19
				Management of local water	C20
	Materials	5	S	Material consumption	C21
				local materials	C22
				Recycled and renewable materials	C23
				Environmental certified materials/ low impact materials	C24
Environmental loads	Sewage	3	S	Sewage flow	C25
				Sewage treatment type	C26
				Reused sewage flow	C27
	Atmospheric emissions	5	S	Substances with global warming potential CO2 emissions)	C28
				Particles and/or substances with acid rain potential (other pollutants emissions, SO2 and NOx)	C29
				Ozone layer damaging potential substances	C30
	Waste	5	S	Waste production	C31
				Dangerous waste management	C32
				Waste recycling	C33
	Exterior noise	1	S	Sources of exterior noise pollution	C34
	Thermal pollution	1		Thermal effect (heat island effect)	C35
Indoor environment	Indoor air quality	7	S	natural ventilation	C36
				VOC`s emissions	C37
				micro-contamination	C38
	Thermal comfort	6		Thermal comfort	C39
	Illumination	3	S	Illumination levels	C40
				Daylighting	C41
	Acoustics	3	S	Acoustic insulation / noise levels	C42
	Controllability	1		Controllability	C43
Durability and accessibility	Durability	3		Adaptability	C44
				Durability	C45
	Accessibility	2	S	Accessibility of handicapped people	C46
				Accessibility and interaction with the community	C47
Environmental management and innovation	Environmental management	5		Environmental information	C48
				Environmental management system	C49
	Innovation	4		Innovative solutions, applicability & integration	C50

5.4 *The application of the LiderA certification method*

The LiderA was directly applied to the case study and once the criteria seemed non-adjusted, it was registered.

5.4.1 *Site and Integration*

Both, soil, natural ecosystems and landscape criteria were only partially complied because:

- The infiltration rate may be reduced due to the fact that a natural sewage treatment plan is more adequate to this remote place than any other form of treatment.
- It may be difficult to control the construction noise and possible disturbance of animal life due to proximity of the oak forest to the field station. In this case and attending to the law that permits the forest cleaning of an area enclosed in a 50m diameter, the noise should have been monitored beyond the 50meters limit which didn't happen.
- Light pollution will be prevented in the ECP but can not be avoided in the public space due to an existing light post.

Furthermore both the amenities and mobility criteria don't apply to a natural area like the Peneda Mountain. The proximity to public transports, shops or heath care is scarce and not financially viable. The closest village, Castro Laboreiro is 4 Km away from Podre and the nearest city is 40Km away (Melgaço). People developed their own medicine, grow their own food, raise cattle, and own a car, (sometimes rent a taxi). Amenities and mobility lack in the Park and are part of a major discontentment that may change with a tourism increase. Nevertheless there is a tourist facility which will soon provide bicycles, horses and canoes for tourism. This will be a major surplus for the area.

Figure 3. ECP: East view of the old (left) and new building (right)

5.4.2 *Resources*

5.4.2.1 Energy

The compliance with these criteria was complex and wasn't fully achieved, for example:

- The use of external insulation is not compatible with the typical exposed granite, forcing the designer to a less energy efficient indoor insulation solution.
- Achieving the glazing area for solar gain often requires addition of new walls that allow south oriented windows
- Ventilation requires mechanical systems
- Strategies used:
- The inevitable interior insulation of the stone walls was compensated by the addition of thermal mass in the concrete (water heating) radiant floor. In the field station the glazing area increased 75% and the ratio between window and floor area is over 10%.

- The windows have wood frames, double glazing with exterior laminated glass, and *Bio-clean* glass (self-cleaning glass); and shutters.
- There are operable windows in all opposite walls and doors have thick air chambers in order to provide air tightness.
- Ventilation is possible even in small bedrooms due to openings on the partitions.
- Daylighting is not enough in the bedrooms but all light bulbs are compact fluorescent.
- Solar panels provide hot water for fixtures, space heating and appliances and a photo-voltaic panel will provide at least 5% of the consumed energy.
- A salamander of pellets/wood will provide backup heating in the winter since biomass is quite available in the region.
- Thermal bridges are avoided in most windows.

Figure 4. ECP: The north façade showing glazing area increase.

5.4.2.2 Water

Potable water is available in the area from a local spring. Nevertheless its consumption will be measured. The rain water is collected in 2 tanks for irrigation and fire fight.

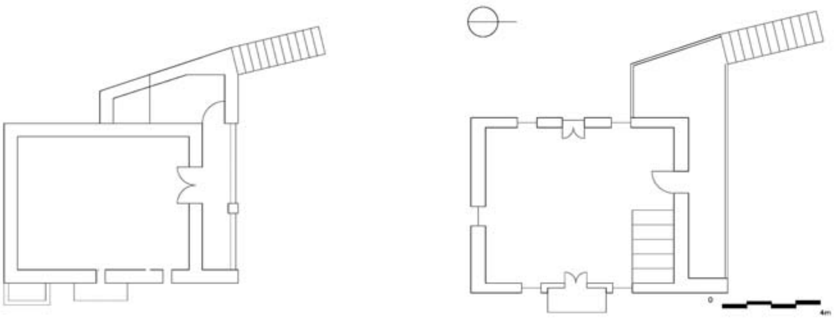

Figure 5. The existing house: ground floor (left) and first floor (right)

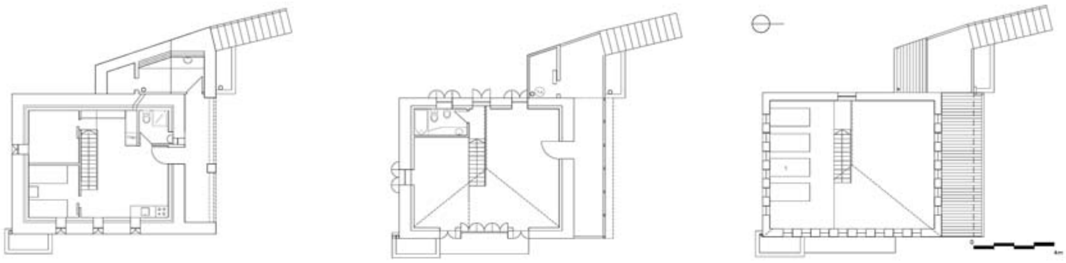

Figure 6. ECP: The new floor plans: ground floor (left), first floor (middle) and mezzanine (right)

5.4.2.3 Materials

The used materials were either, reduced, recycled, local or certified:

- The use of materials was minimized whenever possible by using materials that didn't require finishes.
- Most materials are recycled from the demolition site,
- Many came from the region,
- Some (mostly certified) are imported.

5.4.3 *Environmental Loads*

5.4.3.1 Sewage

Sewage was reduced by installing double flux toilets, water reduction tap systems and thermostatic bath taps. A natural sewage treatment plant will be built in the lot. There is no recycled grey water in this facility. Monitoring will be done and some education will be provided to the users.

5.4.3.2 Emissions

The CO2 emissions of the ECP are not yet calculated but it will depend on the amount of wood (pellets) necessary to backup the solar system installed for heating waters and heating space thru radiant floor. All appliances will be A+ rated (e.g. induction electric cook top, and washing machines that run with solar water). Monitoring will provide accurate figures.

Organic compost will be produced from the forest cleaning waste (50m around the house) mixed with organic trash and ashes from the 2 wood furnaces which will be highly efficient. This compost will be used as garden fertilizer.

Smoking will be forbidden indoors, while outdoors it already is during summer months (from June till September the Park uses this measure for fire prevention).

Materials with no CFC emissions were used in the building.

There will be a manual and a specific place for all harmful substances like lab toxic substances, batteries, lamps and cartridges. Biodegradable cleaning products will be provided to prevent the biological sewage treatment plan from malfunction.

There will be recycling bins for paper, plastic and glass to be taken to the village recycling center.

The noise will be prevented, due to the expanded cork material used both inside the walls and in the roof insulation. Cork flooring will be installed in the mezzanine as well.

Heat island effect will be prevented since pine trunk waste was used for the garden pavement and it is a permeable material.

5.4.4 *Indoor Environment*

The indoor air quality is assured by windows that provide cross ventilation in all rooms. Hopper windows prevent burglar intrusion and are equipped with mosquito nets. In the smallest bedrooms, trickle vents were used in order to achieve proper air renovation rates. Paints were chosen according to their VOC`s emissions e.g. beeswax, linseed oil and water based paints. High radon concentration was detected in the lab therefore epoxy paint was used in the ground floor-pavement as a soil sealant.

Thermal comfort was achieved due to high insulation, water infiltration control, and wind protection from new trees strategic location.

Illumination levels were achieved in all working areas for visual critical tasks.

Daylighting is available in all rooms.

The acoustic insulation is provided from the cork floor and the gypsum and paper panels.

Most windows are operable, with the exception of the upper north windows.

5.4.5 *Durability and Accessibility*

The new interior walls are flexible with the exception of the bathroom walls.

Inside the gypsum wall, the piping is easily accessible since seams and screws are visible.

Durability was ensured by using preservatives in the wood. Self-cleaning glass («SGS-Bioclean») was used for the non-accessible windows.

Accessibility wasn't complied due to lack of space.

The ECP won't be fenced since it is located in a National Park.

5.4.6 *Environmental management and Innovation*

A manual will be provided to the users with some technical info on the ECP sustainable features and a description of its proper use.

The ECP will be monitored during a year, and then will be results will be submitted to an energy and environmental audit and certification.

Some innovative features are the use of light panels made of gypsum and recycled paper and the crashed tiles for the bathrooms.

6 CONCLUSIONS

The certification by LiderA helps designers reaching a more environmental solution although the criteria need adaptation when applied to buildings retrofit which are located within a protected area.

Parameters like site and integration, water, materials and accessibility need to be re-assessed.

The field station allowed to perceive that site and integration should have less weight since location is not an option or choice while retrofitting buildings.

Recycling water in the park is not as important as in the south where it is critical.

On the other hand energy self-sufficiency is critical in a building very distant from the grid. A small biological sewage treatment plant is crucial to avoid underwater pollution in a protected area while space use is not as critical. Other advantages of the biological solution include the fact that it doesn't require electrical energy or technical maintenance.

Recycling materials is more critical in a retrofit especially if it occurs in vernacular architecture on a remote area. Certified materials are still few in the Portuguese market and importing them has a down-side since it increases the material embodied energy. Accessibility is a very big challenge when area constraints are critical like in vernacular architecture. Nevertheless the field station has strong possibilities to be certified and its cost was significantly moderate. The research will soon be completed with more data.

REFERENCES

Anink, D., & Boonstra, C. & Mak,, J. 1996. Handbook of Sustainable Building: EPM

Pinheiro, M. D. 2006. Ambiente e construção sustentável. IA (Instituto do Ambiente).

www.civil.ist.utl.pt/~hpereira/peneda/

www.lidera.info

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Sustainable building structures for housing

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ABSTRACT: Four examples of sustainable mixed building technology, which combine steel and timber in the framing and different materials for cladding, roofing and flooring, in order to obtain highly performance thermo-energetic properties are presented. Some innovative design solutions have been used in these projects. Three examples present single family houses and one block of flats, all of them built in Romania. All the buildings are located in medium and high seismic regions. The paper presents aspects related to design and detailing, as well as solutions for cladding and roofing, including structural features, thermo-energetic performance and cost efficiency analysis.

1 INTRODUCTION

Sustainability is one of the greatest challenges of the modern world. A very well known definition of this concept was given by World Commission on Environmental and Development in 1987: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Sustainability includes environmental, economic and social aspects which contribute to a durable development of the society.

Construction sector play an important role to sustainable development of the world and national economies. Sustainable construction has different approaches and different priorities in various countries. Some of them identify economic, social and cultural aspects as part of their sustainable construction, but it is raised as a major issue only in a few countries.

Sustainable construction can be regarded as a subset of sustainable development and contain a wide range of issue, i.e.: re-use of existing built assets, design for minimum waste, minimizing resource and energy use and reducing pollution.

Steel as material for construction play an important role as component of buildings and engineering structures, and it is used in a wide range of applications. On the other hand, steel is the most recycled material and from the total production in the world, almost half is obtained from waste material.

The steel construction sector has a great deal to offer sustainable development. Like other industrial activities, steel construction work for continuously improvement in terms of sustainability. The following guiding principles for sustainable constructions can be emphasized (Plank & Dowling 2003):

- Understand what sustainable development means for you, you clients and customers;
- Use whole-life thinking, best value considerations and high quality information to inform your decision making;
- Design for flexibility to extend building lifetimes and, where possible, further extend the life of buildings by renovation and refurbishment;
- Design and construct with maximum speed and minimum disruption around the site;
- Design to minimize operational impacts (e.g. energy use);

- Design for demountability, to encourage future re-use and recycling of products and materials;
- Engage organizations within your supply chain about sustainability development;
- Select responsible contractors who have embraced sustainable development principles.

The present paper focuses on the use of light gauge steel framing in housing, considering that sustainable construction technology is used. Steel-framed houses are usually built of light gauge steel framing having different solutions for interior and exterior cladding. This technology is popular and accounts for an important and increasing market share in the US, Japan, Australia and Europe.

Burstrand (2001) presents the reason why to choose light gauge steel framing from an environmental point of view:

- Light gauge steel framing is a dry construction system without organic materials. Dry construction significantly reduces the risk of moisture problems and sick building syndrome;
- Steel, gypsum and mineral wool are closed cycle materials;
- Every material used in light gauge steel framing (steel, gypsum and mineral wool) can be recycled to 100%;
- It is possible to disassemble the building components for re-use;
- Light gauge steel framing means less energy consumption during production than equivalent housing with a framework of concrete poured on-site;
- Light gauge steel framing only uses about a fourth of the amount of raw materials used for equivalent homes in concrete;
- Less waste means a cleaner work site and a low dead weight of building components ensures a good working environment;
- Low dead weight leads to reduced transport needs.

2 SOME REPRESENTATIVE ROMANIAN EXAMPLES OF SUSTAINABLE MIXED BUILDING TECHNOLOGY APPLICATIONS

In recent years, steel framed houses have become a choice for house construction in many European countries, including Romania. Compared with traditional solutions, the properties of the steel skeleton can be exploited to take both technical and economical advantages from lightness of structures, ease of prefabrication, speed of erection and enhanced quality.

On the following, four examples of sustainable mixed building technology, which combine steel and timber in the framing and different materials for cladding, roofing and flooring, in order to obtain highly performance thermo-energetic properties are presented. The first three examples present single family houses and one block of flats, all of them built in Romania. All the buildings are located in medium and high seismic regions. Traditionally, light gauge steel structures were considered non-effective for buildings in severe seismic zones. The examples presented here provide the evidence for the contrary – light gauge steel framed residential buildings really are very effective in seismic regions.

2.1 *Bulzesc's family house*

The structure is a private single-family house built in 1999 in Timisoara, Romania (Dubina et al. 1999, 2000). The built area of the house is 117.5m^2, while the total area is 198.2 m^2. The structure combines steel shear "wall stud" made of C shaped cold-formed profiles placed at 600mm intervals with corresponding floor and a timber roof framing as Figure 1 shows.

The fastening technique is based on self-drilling self-tapping screws of 5.5mm diameter for most of the connections, but in a few special cases classic bolts are also used.

The thickness of the structural walls is 150mm. In order to provide load bearing capacity against horizontal loads bracing straps were used on both sides of the wall panels. The thickness of the straps had to be small in order to have a flat surface for the finishing.

Floors have been realized as dry floating-floors. The main joists were C profiles and the corresponding layers of the floor being: hard-wood parquet (2.2cm), phonic insulation (2.5cm), supporting wood decking (5cm) and gypsum board ceiling (1.25cm).

From the architectural point of view, there is great advantage due to light partition walls and high strength of the joists, leading to freedom in subdividing the internal space following functionality rather than structural requirements and allowing large free spans.

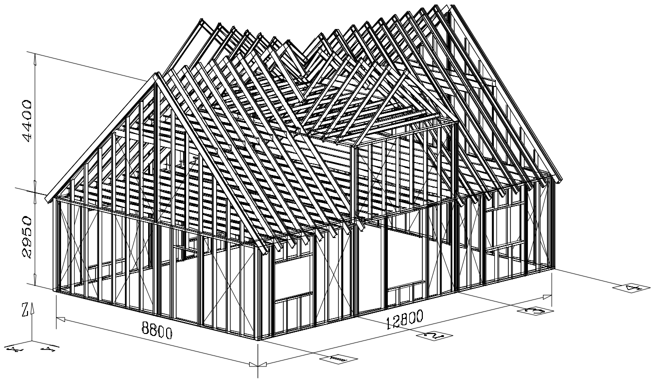


Figure 1. The main load bearing elements of the structure

Adequate thermal and sound insulation was achieved by using high performance materials and by paying attention to the finishing details to ensure air tightness both to the exterior and between rooms. Against impact noise the floating floor solution adopted was found to be very effective. The following layers have been used for roofing and cladding (see Figure 2):
Cladding (in/out): gypsum board (12.5mm); vapor barrier (0.5mm); Lindab C150/1.5 joists; mineral wool (150mm); Heratecta wood particles and cement (50mm); plastering (20mm);
Roofing (out/in): asphaltic tiles, asphaltic bitumen membrane (3mm); OSB board (20mm); ventilation layer (50mm); SOLFLEX aluminum layer; basaltic mineral wool (200mm); timber rafter (250x50mm/600mm); vapor barrier (0.5mm); gypsum board (12.5mm).

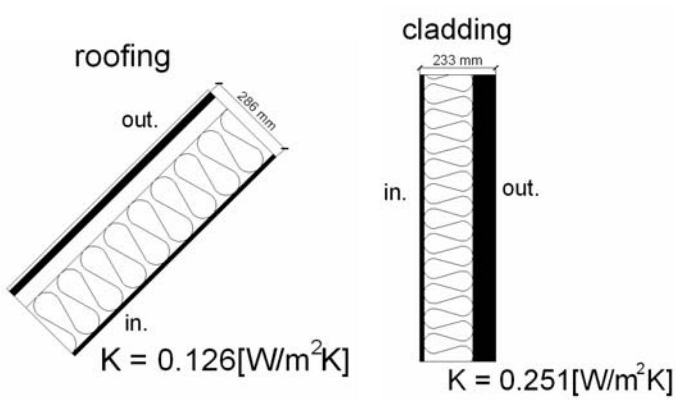


Figure 2. Layers used for roofing and cladding

For the external finishing there can be options for vernacular or modern appearances. In this case the owner's option was for a traditional look which was obtained using traditional exterior and interior finishing materials (Figure 3).

Figure 3. Skeleton of the structure and completed house

Following a cost analysis, the steel structure is identified to represent around 20% of the total cost, the main costs being spent on finishing (see Figure 4).

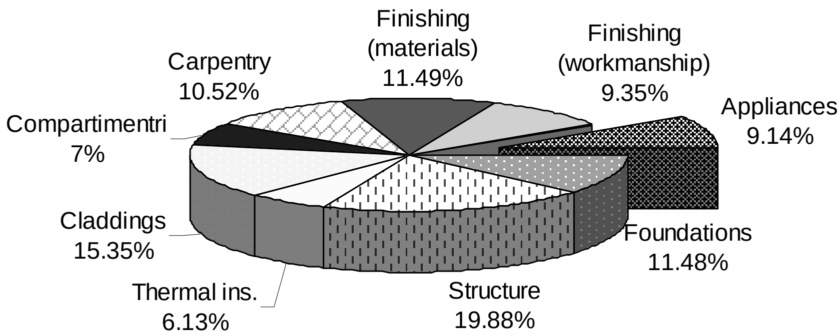
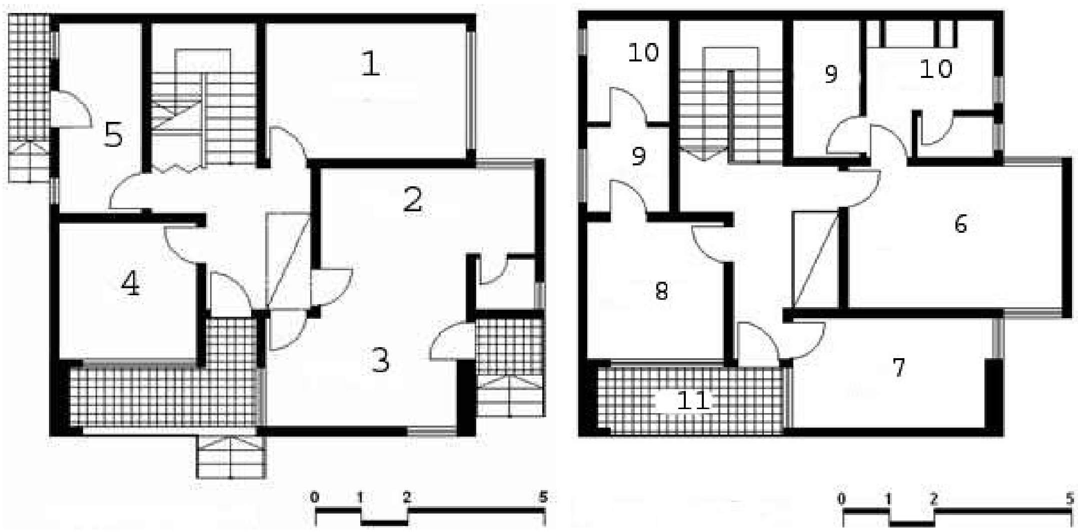


Figure 4. Cost distribution for the house

2.2 *Constantin's family house*

The structure for this private single-family house was built in 2003 in Ploiesti, Romania (Access Steel 2006). The two main characteristics of this two-storey building are the use of light steel framing for a private home, and an architectural solution shaped by a constrained site.

From the architectural point of view, the main challenge of the project was to fit this private home on an irregularly shaped lot of only 168m^2. The resulting cube-like building measured in the end 84m^2 of built area on each of the two floors (see Figure 5), going up to the maximum allowed by city regulations. Given the proximity of the buildings on the adjacent properties, the next difficulty consisted in finding the balance between the right amounts of views, natural light and privacy. Two skylights located above the stairwell and the hallway, were placed to provide a light shaft, in order to enhance the centre.



Lower floor plan: 1. dining room; 2. kitchen; 3. family room; 4. den; 5. laundry;
Upper floor plan: 6. master bedroom; 7. library; 8. bedroom; 9. dressing; 10. bathroom; 11. logia
Figure 5. Lower and upper floor plan of Constantin's house

The structure, presented in Figure 6, is a two-storey single family house. Because the building seats on the property limit, it was impossible to provide window openings on that side. This was also one of the reasons for the roof being made with a single slope, the high of the building going from 9m to 10.5m. Each floor has approximately 2.75m in high and the slope of the roof was 30°.

The structural skeleton is made of light-gauge C shaped profiles (C150/1.5) at 600mm intervals, with a thickness of 1.5mm, fixed with 4.8mm diameter self drilling screws. The height of the profiles is 150mm, which governed the thickness of the walls. In order to withstand horizontal actions and to provide stiffens and strength the walls were stiffened using 10 mm thick OSB plates provided on both sides of the structural walls (Figure 6b).

The load bearing beams in the slab are C200/1.5 profiles at 600mm intervals, resulting from the condition to control the vibrations of the floor rather than from strength conditions. Roof purlins are Z150/1.5 profiles at 1200mm intervals. The floor diaphragms were originally designed to be based on the same principle of covering with OSB, this solution being changed into sheathing with trapezoidal steel sheaths both at the level of the slab and at the roof. No concrete topping was used on the slab.

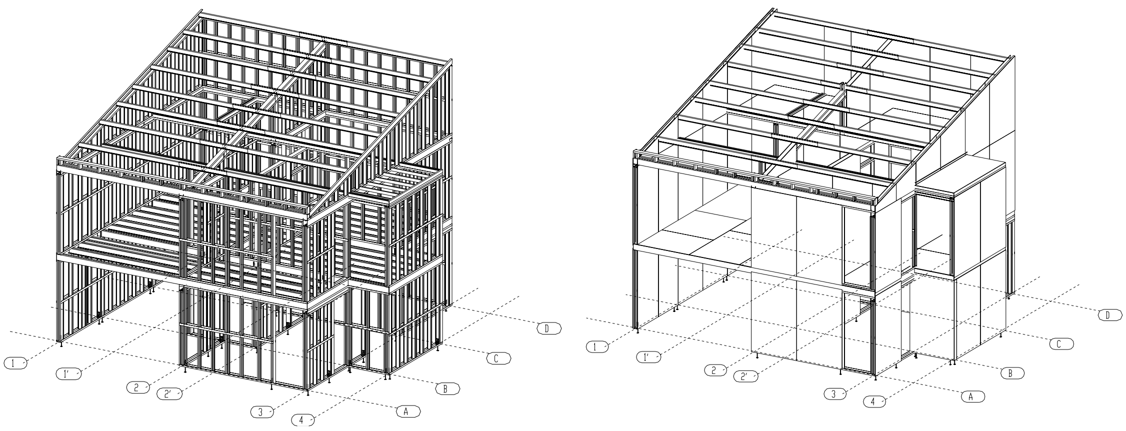


Figure 6. a) Steel skeleton of the structure; b) Skeleton with structural OSB sheeting

The following layers have been used for roofing and cladding (see Figure 7):
Cladding (in/out): gypsum board (12.5mm); vapor barrier (0.5mm); OSB board (15mm); Lindab C150/1.5 joists; terwoolin mineral wool (150mm); OSB board (15mm); basaltic mineral wool (40mm); mineral plastering BAUMIT (8mm);
Roofing (out/in): waterproofing membrane reinforced with mineral aggregates (3mm); waterproofing membrane (3mm); OSB board (20mm); basaltic mineral wool (150mm); Lindab corrugated sheet (LTP 45); Lindab C200/1.5 profiles; vapor barrier 0.5mm; gypsum board (12.5mm).

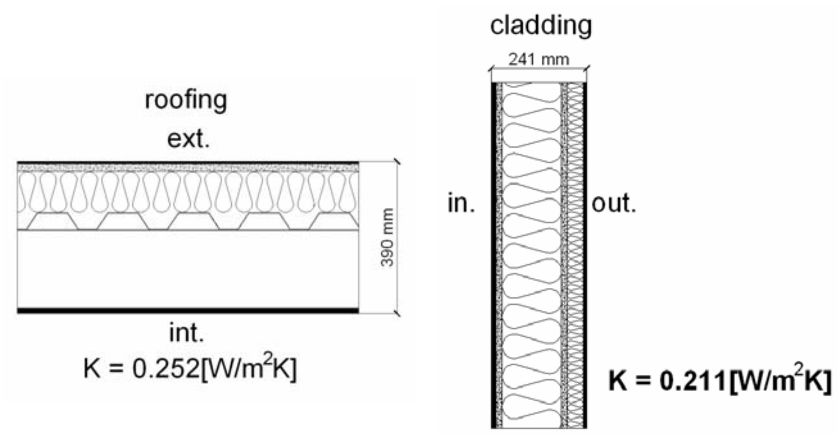


Figure 7. Layers used for roofing and cladding

Figure 8 presents exterior and interior views of the completed house.


(a) General view (b) Interior view – staircase
Figure 8. Constantin’s family house

2.3 *Carmen’s family house*

The structure is for a private single-family house built in 2006 in Timisoara, Romania. The main structure is made of steel profiles, while the floor and roof is made of timber elements. The building combines modern and traditional materials and techniques, in order to obtain a typical Transylvanian village house (see Figure 9).


(a) the main steel skeleton (b) the steel skeleton with timber floor


(c) General view (d) Roof detail
Figure 9. Carmen’s family house

The following layers have been used for roofing and cladding (see Figure 10):
Cladding (in/out): gypsum board (12.5mm); vapor barrier (0.5mm); mineral wool (50mm); vapor barrier (0.5mm); ventilation layer (100mm); mineral wool (100mm); timber joists (50x200mm/500mm); OSB board (20mm); Heratecta wood board (75mm); plastering (20mm)
Roofing (out/in): tiles of wood, battens (50x50mm); boarding (20mm); SOLFLEX weather resistive barrier; OSB board (20mm); ventilation layer (100mm); vapor barrier (0.5mm); basaltic

mineral wool (200mm); timber rafter (300x50mm/600mm); vapor barrier (0.5mm); gypsum board (12.5mm)

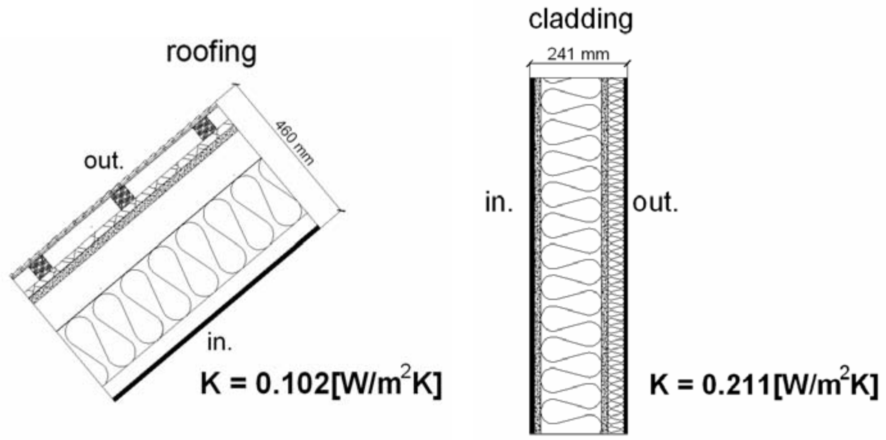


Figure 10. Layers used for roofing and cladding

2.4 *Block of flats*

The structure is a block of flats built in 2006 in Timisoara, Romania. Architectural views are presented in Figure 11. The keys for this kind of structure are built-in flexibility and energetic efficiency. The main structure is made of steel profiles with light floors. Column-free, uninterrupted floor plates are the optimum answer to allowing users to optimally reconfigure internal areas and this generally means long-span solutions (see Figure 12).

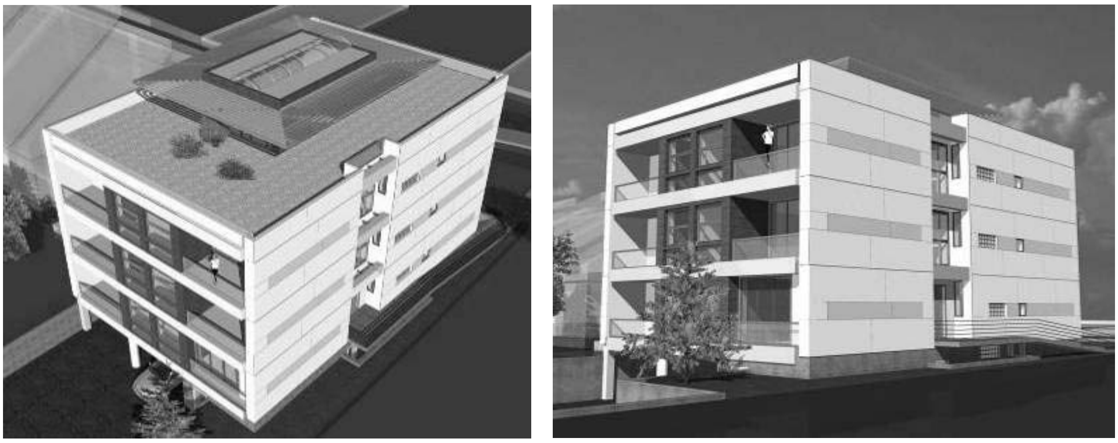


Figure 11. 3D architectural views

Figure 12. Structure during erection

The following layers have been used for roofing and cladding (see Figure 13):
Cladding (in/out): gypsum board (12.5mm); vapor barrier (0.5mm); basaltic mineral wool (80mm); gypsum board (10mm); ventilation layer (80mm); OSB board (15mm); basaltic mineral wool (100mm); C150/1.5…600mm joists; Al profiles; MEG plastic boards (8mm);
Roofing (out/in): gravel (50mm); rigid mineral wool (100mm); light concrete (50mm); corrugated sheet (45mm).

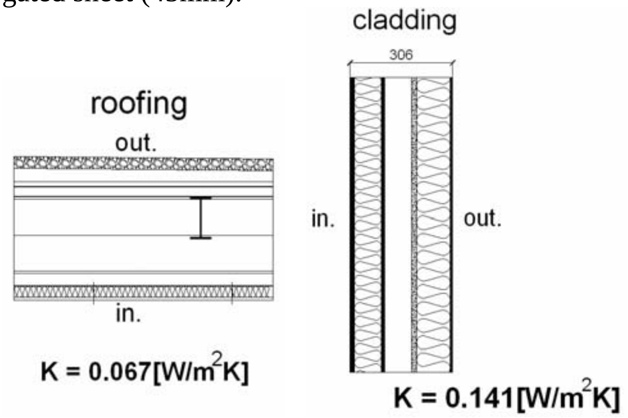


Figure 13. Layers used for roofing and cladding

3 CONCLUSIONS

The four examples presented in the present paper represent a complete sustainable technology of high performance thermo-energetic materials for cladding and finishing and use productive and qualitative technology both for fabrication and erection. It enables to obtain flexible partitions and allows for further up-grade, easy modifications and/or development.

All the buildings are located in medium and high seismic regions. Compared with traditional housing technologies, steel frame houses are, besides their technical advantages and enhanced quality of both structure and finishing, really cost effective, too.

REFERENCES

Access-Steel 2006. SP024a-EN-EU *Case Study: Constantin's Family House, Ploiesti, Romania*. www.access-steel.com.

Burstrand, H. 2001. *Light-gauge Steel Framing for Housing*. Swedish Institute of Steel Construction. Publication No. 170.

Dubina, D., Fülöp, L. & Zaharia R. 1999. Floor and wall bracing systems for steel framed houses. *Proceedings of the 6th International Colloquium on Stability and Ductility of Steel Structures - SDSS'99. Timisoara, 9-11 September 1999.* 485-492.

Dubina, D., Fülöp, L., Ungureanu, V., Szabo, I. & Nagy, Z. 2000. Cold-formed steel structures for residential and non-residential buildings. *Proceedings of the 9th International Conference on Metal Structures. Timisoara, Romania, 19-22 October 2000.* 308-317.

Plank, R. & Dowling, J. 2003. Sustainable Constructions. *Steel Buildings.* BSCA, Publication No. 35/03.

Sustainable Steel Construction: *Building a Better Future*. The Steel Construction Institute. http://scinews.steel-sci.org/articles/pdf/SSC.pdf

United Nations 1987. World Commission on Environment and Development. *Our Common Future* (The Bruntland Report) Oxford University Press, Oxford and New York.

Sustainability of Constructions. Van Abbemuseum, Eindhoven

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ABSTRACT: Eindhoven is a city of the Netherlands. Van Abbemuseum is a newly renovated museum in 2003. The historical museum building, dating from 1936, is designed by architect Kropholler, and architect Abel Cahen designed the integration into the spectacular new wing. Also the old part of the museum is welcoming to the visitors from the main street, while the small pink aluminium cladded entrance house is an entrance to the new wing.

In this case study, the sustainability topic will be discussed how they could manage to hold the old building still standing for the entrance part of the whole museum complex, old and new. During the observations, the advantages of the new construction system will be underlined to show how a new wing can be successful in the sustainability of old constructions from the use of new materials as iron and steel in both structural solutions and also in constructional details.

1 GENERAL INTRODUCTION

1.1 *Van Abbemuseum*

The Van Abbemuseum is one of the popular museums to lead for modern and contemporary art in Europe. It was opened in 1936. And since that date, there has been many acclaimed exhibitions and built an extensive, internationally renowned collection of more than 2700 works of art. The reputation of the collections is depending on the quality of the individual works of art, among which are masterpieces by Picasso, Chagall, El Lissitzky, Beuys, Weiner, Gordon and McCarthy.

The Van Abbemuseum officially reopened in 2003, after the completion of the renovation of the old building with the addition of the expansive new wing. In the old building, temporary exhibitions, about general politics and special concern alongside focused presentations of individual artists are exhibited. In the new building, Plug In, a radical new approach, has been developed to exhibit the famous collection. Also in the new building, Living Archive, which includes a series of documentary exhibitions based on the museum archive, is located.

The two contrasting aims of radicalism and hospitality, experimenting with the subjects and forms of exhibitions and museum projects, are the aim of the Van Abbemuseum over the coming years to work with.

1.2 *The spaces in the plan of Van Abbemuseum*

The new building and old building are having lots of different spaces due to functions. Towering part is a great chance to see the overall view of the new entrance from the back side of the building, linked to the city center, from the inside of a pink colored hub, having an aluminium structure. River Dommel widened to create a charming entrance towards museum via café. The library is an opportunity to search inside of a digital archive about art and everything. The auditorium gives a nice chance to watch the movies, sitting over the red comfortable chairs. Bookshop serves you in every manner, by selling books about art, building itself, cities and by selling specially designed objects as souvenirs. The entrance of the bookshop is covered with the stairs up and there are nice cartoons over the surrounded walls. The shelves of the objects can be moved to open and to close the bookshop everyday

Photograph 1. New entrance to Van Abbemuseum through café in the new building (photo by Y.K.Aktuglu, 12/2006) .

1.3 *The newly designed spaces*

The newly designed spaces, including the administration section, the library, and the cafeteria are playing a very important role to support the life of the museum for today. The design principles for making a museum sustainable in today's conditions require the logical use of materials and also the contrast of the materials as togetherness of stone cladding and glass, or steel supporters and glass.
But esp. the use of structural steel is making the value increase in the name of functionality of a museum building, coming from past and still living today.

2 STRUCTURAL STEEL USE IN THE SPACES

Water welcomes the visitors, both to the new entrance from the inside of the pink hub, with an aluminum structure and also with a bridge over the water, from the front of the library towards the main entrance in front of the old building. For the strength of the structural steel is very high, then the new structural system in first and second manner as main structural system and secondary structural elements, has effect on the spaces, created newly and also it makes them be more enriched.

2.1 *Café*

The steel stairs, inside the café for up, is made of the lightest material in a very economical and very logical construction technique. The glass holders of the stairs are connected to the steel plate with double screws, and it ends with another steel plate at the top of the glass to hold them.

The glass facade is being carried by the steel connection elements, passing the loads to the columns behind the glasses, supported by the steel mullions. In this way, a transparency is gained for getting more daylight inside the café.

The first floor of the café is going out from the façade to create a balcony outside.

2.2 *The openings*

From exhibition halls toward outside, there are some openings as doors with glass and additionally a glass attachment with structural steel framing, having also a steel decking over the river. This adds a value to the new building with its brilliant effect from outside, and with a smiling light toward inside.

The connection level between old building and new building is constructed with structural steel material, with nice details, creating a flying floor again over the river.

The opening towards the back side street is covered with glass having lots of writings on it as a security of the visitors not to crack the transparent surface.

2.3 *Library*

The opening, from the library basement level toward outside above the river, is constructed with circular hollow section columns or let's say it as mullions to carry the loads of glass cladding with additional detailing, creates an attractive space to call the readers to that place to read their books inside of the nature.

There is a very light booking section with steel shelves to carry the books, with glass and structural steel cantilevered corridors in front of the shelves, and there is a very light stairs connecting the basement and ground level of the library with light steel detailing. The advantage of steel shelving is giving you an nice working space with the very thin shelf thickness. All of these are enough to represent an information area in a very shinning position also by getting the full daylight from the top roof.

2.4 *Steel bridge*

Steel bridge is connecting you to the main entrance in the old building by making you fly over the river.

2.5 *Glass façade*

The courtyard named "above beyond below" is covered with glass and steel mullions, to create a semi-closed space without a roof cover to make people be available to attend to a concert in this courtyard.

The whole façade of the new building is constructed with glass and steel mullions to have a flowing mirror surface to make the new addition more brilliant around the water composition as a link with the river.

2.6 *Entrance from the back side to the new building*

At the back side of the museum, there is a very charming and attractive small aluminium hub in pink, calling you to come inside by passing the wooden covered, in floor, garden terrace of the café such as floating over the river. The going out upper floor of the café through the glass facades gives you another exciting moment in the manner of a clue to be a sustainable building in future.

The flat metal lines over together with the stone cladding of the new building give an impression as being ready to fly.

2.7 *Vertical circulation spaces covered with glass and steel trusses*

There is a main and dense vertical circulation space full with daylight coming inside through the glasses, carried by hanged structural steel trusses, in white color, composed with nice details as vertical wall participants and also nearly horizontal roof claddings.

In the next space for stairs, also at the top there is an opening with steel and glass to get daylight inside.

From the top part of the mid- vertical circulation space, it is nice to have an idea about toward the café and the other entrance door in pink near the river, by looking out inside the glass cladding, carried by circular hollow sections, replaced in horizontal position.

Photograph 2. An overview to Café decking over River Dommel(photo by Y.K.Aktuglu, 12/2006) .

2.8 *The book shop*

The book shop is not only a very attractive selling place for the very carefully prepared souvenirs, but also the whole door pieces in the form of shelves to exhibit the goods are calling you to visit it. These door pieces are turning in their axis to be open during the day, and later to be closed in the evening.

2.9 *Auditorium*

There is a small steel spiral stairs to go up part of the auditorium, creating an attractive magnet inside a closed and dark space.

2.10 *Additional features*

There is not any addition to the old building as new. The normal height of the old building is accepted as they are since the first day. And the walls are brick, and they are being melted between the other urban texture.

At the other part of the complex, the new feature is being bold with totally new wings. It can be only seen the top of the clock tower of the old building.

Even though it can be a dark afternoon, the metal flat lines in vertical placement are enough effective to present the existence of the new building with the help of the water of the river Dommel.

Photograph 3. The back side view of Van Abbemuseum through new wings (photo by Y.K.Aktuglu, 12/2006) .

Photograph 4. Main entrance to Van Abbemuseum from old building(photo by Y.K.Aktuglu, 12/2006) .

3 CONCLUSION

3.1 *The building itself*

The properties of the buildings, both old and new are enough capable to be sustainable in the future. They are in contact with nature, when it is available to get an opening to out by the use of structural steel and glass.

The functions of the spaces seem to be in service for all days of the future times, including museum's potential of digital archives.

The café, over the River Dommel widened, is totally a unique atmosphere to live in a preparation section before the real art.

The library, full with documents, is a great resource for researches.

The auditorium is another magnificent space to be linked with the movable artificial life, on the screen.

The bookshop is a miniature of the global museum life.

With all these parts, Van Abbemuseum is a successful candidate in the list of the museums, from the point of sustainability.

3.2 *The value added to the city in the meaning of sustainability of the Van Abbemuseum*

The activities of Van Abbemuseum is attracting the people living in Eindhoven, and the students studying in TUeindhoven, nearer to art titles with exhibitions, workshops, musical performances, etc. with free entrance. This kind of occasions are making the city life more enjoyable and more cultural, in a daily life scenario. For the presence of the old building of Van Abbemuseum, it is aimed to make its function as museum to stay in a sustainable manner for other generations by enlarging its capacity.

The Van Abbemuseum is a very successful sustainable museum complex, supported and riched with the use of the structural steel to make its spaces be in contact with nature at maximum.

3.3 *References*

several visits, on different times, to Van Abbemuseum on 12-15.11.2006
several guide books about Eindhoven
http://www.vanabbemuseum.nl/engels/gebouw/gebouw.htm

Sustainability of Constructions. Suleyman's Mosque, Istanbul.

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ABSTRACT: In the Turkish Architectural History, Mimar Sinan has the most important place to define the landmarks. The Mosques, the bridges, the kulliyes(with a mosque in the heart of the kulliye as an extensive assembly of religious schools and buildings housing social functions), etc. of Mimar Sinan are coming today along a more than 400years period. The compositon of the full dome and semi domes is very important for the rich space value under. The additional structural elements for controlling the praying sound to God prepare a fully solved situation in the meaning of acoustical control. In the paper, after the definition of the complex in the meaning of history and in the meaning of space compositions, its structural system in the context of building materials and constructional details, the reasons of its acoustical performance and the degree of the efficiency of the daylight use will be explained.

1 GENERAL INSTRUCTIONS

Not only the construction systems, materials and details, and also the importance of acoustical property of the buildings and the outside areas and the use of daylight inside and outside of the building made the products have more statual manner. The use of masonary, brick and stone together with iron bars are the construction materials for the envelope.

The amounts and the size of the windows for daylight are the main elements for a more sacred athmosphere while using the space for meeting with God. The LCA and the LCC situation of a such building complex as Suleyman's Mosque and education complex in the meaning of sustainability has a great importance in today's construction world.

For these reasons we are aimed to make investigations about Mimar Sinan’s Suleymaniye Cami in Istanbul, Turkey.

1.1 *Mimar Sinan(Great Architect Sinan)*

The date of birth of Mimar Sinan remains uncertain, but is generally accepted to be 1490(Egli, 1992). He is coming from the village of Agırnas near Kayseri in Turkey. He says that he saw the monuments, the great ancient remains, from every ruin he learned, from every building he observed something. The maturation of Sinan can be followed in the miraculous deployment of Suleyman’s great mosque and kulliye(can be accepted as university city). Most of Sinan’s legacy survives(some250 out of 450 buildings). This gives us a great chance to follow the great architect’s development and artistic ascertion. The works, he did in his life, give him the title “The Great Architect Sinan (Koca Mimar Sinan)”.

1.2 *Suleyman the Lawgiver, 1520-1566*

Suleyman(Kanuni) who was the tenth Sultan of the Ottoman Empire, succeeds eminent rulers who, by their political savvy and strategic brilliance, secured a vast empire. When he was the Sultan, the Ottoman realm reaches great extension.

1.3 *Suleyman’s Mosque, Kulliye, Istanbul,*

Suleyman’s Mosque, Kulliye, Istanbul has an overwhelming impression. It is not only the calculated setting of the mosque on the precious site, but also the very well planned kulliye, created a splendid stage that assures its magnificences.

Photo 1. The view of Suleymaniye Camii from Galata Köprüsü over Haliç/Golden Dolphin, (photo is taken by Yesim Kamile Aktuglu, on 28th of April 2007)

2 SULEYMAN'S MOSQUE, 1550-1557

2.1 *The history and the description of its plan*

During the classical period mosque plans changed to include inner and outer courtyards. The inner courtyard and the mosque were inseparable. The master architect of the classical period was Architect Sinan, and he started a new era in world architecture, creating 334 buildings in various cities. Mimar Sinan's first important work was the Sehzade Mosque completed in 1548. His second significant work was the Suleymaniye Mosque and the surrounding complex, built for Suleyman the Magnificent. (The Selimiye Mosque in Edirne was built during the years 1568-74, when Sinan was in his prime as an architect.)

During the mid-16th century, the Turkish sultan known as Suleyman the Magnificent added much territory to the Ottoman Empire through conquest. Due to the wealth he gained, he ordered a mosque appropriate to his title. The Suleymaniye Mosque was built on the order of sultan Suleyman and was constructed by the great Ottoman architect, "Architect Sinan". The construction work began in 1550 and the mosque was finished in 1557.

Suleymaniye Mosque is considered to be a kind of architectural answer to the Byzantine Hagia Sophia, commissioned by the Emperor Justinian. Sinan's Suleymaniye is a more symmetrical, rationalized and light-filled interpretation of earlier Ottoman precedents, and assimilates so many aspects of Renaissance architecture (Goodwin, 1971).

The mosque itself was situated in the middle of a kulliye which was constituted of a a caravanserai, a public kitchen (imaret) which served food to the poor, a hospital (darüşşifa), four Qur'an schools (medrese), a specialized school for the learning of hadith, a bath-house (hamam), Mosque Precint, Latirns, and coffee houses, apart from the main mosque with the praying hall, and the arched courtyard. It was situated at the top of the third hill of the city above the Horn, and dominated this area with its significant dome, and added a terrific silhouette among the city.

The mosque complex had two main parts, firstly the courtyard area, and secondly the main praying hall. The courtyard is the preparation area for the religious rituals (Namaz). The courtyard was surrounded by porticos, and the porticos were supported by minor domes and arches. An Ablution fountain was placed in the center of the courtyard. One can enter to the courtyard from the outside with three defined gates- portals. After entering to the praying hall, one can feel an approximately square space surmounted by a central dome. To the north and south the dome is supported by two semi domes, to the east and west it was supported by arches with tympana filled with windows. The dome-arches rise from four great irregularly shaped pillars. Up to this point the plan scheme follows that of Hagia Sophia, but beyond this all is different. To the east and west directions, there are 10 minor domes supporting the main domes and arches. Two galley spaces reached from the inside of the mosque is situated under these minor domes, adding a third dimension to the interior. Inside there are also the mihrab (prayer niche showing the direction to Mecca-kıble) and the mimber (pulpit) made of finely carved white marble.

In his work of establishing the four Minarets defining the four corners of the Courtyard, he had achieved a classical symmetry, the minaret elements were beautifully proportioned with the two taller at the junction of the arched courtyard and the other shorter two on the front façade of the courtyard rising with ten balconies, representing Suleyman's being the 10^{th} Emperor of the Ottoman Empire. This contrast manner emphasize the axial movement of the monument from south to north direction, formed a grandly strong silhouette on the hill above the Horn.

2.2 *The Structure*

Suleymaniye is constructed on the third hill of the seven hill city, Istanbul. The construction for mosque had started in 1549 and completed by 1557. The main dome has constructed on four arcs over huge four columns. The white marbles was brought from Marmara Island and the green ones were taken from Saudi Arabia. The mosque has 138 windows which have marvelous handwork.

The plan dimensions of the Suleymaniye Camii is 58 meters in width and 59 meters in length. The main dome, which has diameter of 27.25 meters and 53 meters hight, is supported with four columns. These columns are symbolized in the name of four Muslim Caliphs. The two of the columns are taken from Byzantium Palace, the third one is from Kıztaşı and the last one is from Jupiter Temple in Baalbek. The heights of the columns are 9.02 m with the diameter of the 1.4 m. The approximate weight of the each column is 30 t and carrying about 8000 t total loads.

The weight of the main dome is about 1000 t. The mosque was built at the glorious time of the Ottoman Empire. However, the diameter of the dome was not greater than the diameter of Hagia Sophia dome. The complex has four minarets. Two of the minarets has 3 balconies with 76 m. height and other two minarets have 2 balconies with 56 m. height.

The minarets have a total of 10 galleries which is also represents that Magnificient Suleyman was the 10^{th} Ottoman Sultan. The mosque complex not only consists of the praying hall(cami) and courtyard (avlu), but also includes a caravanserai or seraglio (sarayı; han), a public kitchen (imaret) where food is given to the poor people, a hospital(darüşşifa), four Qur'an schools (medrese), a specialized school for the learning of hadith, and a bath-house (hamam). The tombs of Magnificent Suleyman I, his wife Roxelana(Haseki Hürrem), his daughter Mihrimah, his mother Dilaşub Saliha and his sister Asiye are located behind the main mosque in the garden. The great architect Sinan's tomb is outside the northward of the mosque walls.

Outside of the mosque there is a courtyard with 24 columns. The six of the columns are granit, six of them are dark granite, and the other 6 of them are Marmara granit. Their approximate weights are 10.6, 4.1, 3.8 for per column respectively. The last six columns are short and have gained a pyramid form to the structure.

The mosque is designed so detailed that air circulation of the mosque is high enough to clean the candle smoke and have sufficient air flow. Even the candle smoke is collected and converted to be used in ink production.

2.3 *The stabilizing structural element, iron baring*

Nearly all of the arches, inside and outside of the mosque, above the columns to collect the loads coming from domes, and semi-domes, are having iron bars for tension loads to keep the whole structure in a steady situation, coming from the mid of the main dome to the bottom of the columns. These iron bars, can be double in main places of the inner and outer spaces.

In the capital of a column, there are many structural features. The bronze collar is used both at the base and in transition from shaft to capital, which is a serviceable instrument. The fixing of the capital to its place is done with an iron pin and no mortar is used. The insertion of an iron pin and a lead plate is a normal intersection point to provide a flexible connection, which is vital to prevent transmission of earthquake shock waves (Egli, 1992).

2.4 *Daylight*

The mosque is important in Islam religion and the use of light is very important in the mosques. Architect Sinan had used the light as a design element in his mosque designs. His mosques are lightened with the daylight with many windows on the walls. These windows are placed in different levels as lines from the bottom of the dome to the ground level and they have different sizes, shapes and light transmittances.

There are 249 windows in the mosque which are placed in 7 levels.(Kuran, 1986) The high number of windows also show the importance of the mosque and the power and wealth of both the Ottoman Empire and Kanuni Sultan Suleyman due to the fact that the production of such big window glasses at those times (around 1550) was very difficult and expensive. Glass technology was accepted as a prestige technology that palaces and governments supported. (Kucukerman, 1998) There are many windows in the mosque.

There are notebooks which were written during the construction of the mosque. The details of the construction were written in them. According to these notes, 1417 people worked in the construction of the windows and glasses. 540 of them took 12 kurus (money unit of that time), 70 of them took 10 kurus. The payments are grouped into 5. The highest paid group took 12 and 10 kurus, and these were the most talented workers group. They were 610 workers. This shows that these workers were the most talented craftsmen, and their number was more than their helpers. (Kucukerman, 1998) The other groups and their payments are shown in the table below:

Table 1. The worker groups of Suleymaniye Mosque construction and their payments*

Number of workers	Amount of payment
540	12 kurus
70	10 kurus
15	9 kurus
25	8 kurus
124	7 kurus
153	6 kurus
387	4 kurus
97	3 kurus
6	2 kurus

* (Kucukerman, 1998)

This shows that many talented workers were used to finish the construction in a very short time and that the architect wanted the mosque to be of high quality. Therefore this made the mosque live and sustain for hundreds of years with the same quality.

The windows on the bottom of the dome lighten and emphasize the dome. These are arched windows.

The 3 levels of windows on the rear tympana walls that are under the great arches provide intensive daylight to the interior. It is seen that Architect Sinan tried to open as many windows as possible due to the different shapes which help to open more windows. There are 4 circular small windows in the rear parts of the wall where he could not open the regular arched windows. And there are 19 regular arched windows on each of these two walls together with these 4 circular small windows.

The semi-dome supporting the main dome on the chancel (Mihrap) side also has a line of arched windows. There are also arched windows on this semi-dome. The two little supporting semi-domes also have arched windows.

The chancel (Mihrap) wall is divided by windows on 3 levels but these windows' glasses are decorated and colored (called as vitray) to prevent the daylight entering the building and disturbing the praying peoples' eyes. These windows are also in different shapes and different sizes in order to open as many windows as possible and to break the monotony of the plain wall.

The level of the sitting people who are praying is lightened with the use of big rectangular windows. All the windows except these are protected with honeycomb shaped curtains which help to diffuse the daylight entering the building through the windows. This helps to reduce the excess illumination and the discomfort of the eyes. And also help to provide a mystique atmosphere inside.

There are less windows on the entrance side. There are two reasons of this. One of the reasons is that this is the northern side and it is the coldest side. Therefore Sinan had designed less windows on this side in order to keep the interior warmer in the winter, because this is a very huge building with many cubicmeters of space and it is very difficult to heat up the interior. The other reason is spiritual: people are facing south when they are praying, that is due to the fact that Mecce is in this direction. Therefore there mustn't be much prevention between the praying people and the Mecce. Because of this, there is not much need to open many windows on the northern side, and Sinan opened just enough windows.

Windows are used generally to lighten the mosque interior. But there is the fact that many people use this building. Not only the people's breathing, but also the soot of the burning candles and lamps at nights and dark winter days would have polluted the interior air. So this brings the ventilation and air-cleaning problem. But Architect Sinan had solved this problem with a very good and efficient solution. He had made a room at the top of the entrance door which takes and gives the polluted inside air out. The soot is collected at the ceiling of this room and it is used to produce ink. It is said to be the best quality ink. (Kuban, 1997)

2.5 *Acoustical Performance*

One of the most important design criteria for such a huge volume is acoustics in terms of obtaining both silence for praying and indoor acoustic quality. In Mosques, music practice is usually not used while praying. It is more important to be concentrated as much as possible during the pray. But, on religious days, a special session named as 'mevlid' is held and in this session musical function is more emphasized. Another activity is speech, which is made by muezzin (religious officer) in the mosque. These different types of activities need different acoustical properties.

If we think of the interior noise level, it was probably not a big problem to obtain the low levels of noise in 16th century, since there was not a noise problem that we have today. So, it could be ignored at those times. But even today, the thick stonewalls and limited openings prevent unwanted sound coming to inside.

On the other hand, if we think about the indoor acoustical quality, having approximately 88000 m3 volume, and having a dome shaped roof above, Suleymaniye Mosque is expected to have some acoustical problems. But, it can be said that Sinan was obviously aware of the importance of the acoustics, while designing Suleymaniye Mosque. He realizes such a complex's problems and tries to solve them.

He tries to prevent echoes, which are caused by dome, by using some ceramic containers (Helmholtz/ Cavity Resonators) in the forms of pots (Topaktas 2003, Kayili 2005). The dome form is one of the most difficult forms in acoustics. Because of the concave forms of the domes, the incident sound energy does not go out without reflecting several times in the dome. Because of this, the reflected sound energy from the dome reaches back to the room with a time delay. So the result is echoes or noise in the room and reduction on the percentage of intelligibility. Cavity resonators, placed in a dome, prevent the reflection of sound energy and reradiate it throughout the room (Kayili, 2005). Today's measurements show that Suleymaniye Mosque has approximately 6-7 seconds Reverberation Time at middle frequencies (Topaktas 2003, Fausti et.al. 2003). This value can be long for rooms for speech, but it is considered quite reasonable for Suleymaniye. But, this value could be measured lower than today when the time Mosque built. During the restoration studies over the years, sealing the openings of ceramic containers and changing the original material have resulted different acoustical conditions from the original one.

Besides this, selection of surface materials has also a very important effect on acoustics of the room. And it is believed that Sinan also made his decisions with this knowledge. Suleymaniye Mosque has mainly plaster and stone interior surfaces. And floor is completely covered with highly sound absorbent material, thick carpet.

Also, while enlarging the volume of Suleymeniye, Sinan tries to increase sound power by a number of sources. For this purpose, he placed the muezzin's mahfil (a gallery for the call to prayer) next to the southwest pillar and in addition, he added small mahfils (balconies) to the two north pillars (Kayili, 2005). Addition of mahfils also show that the awareness of the need for extra sound power during the design process.

2.6 *The effect of sustainability*

Sustainability is becoming a central concern. It is a concern that has grown out of wider recognition that rising populations and economic development are threatening a progressive degradation of the earth's resources.

As being architects and engineers we have to think about the construction industry. The industry operates globally, and on a much larger scale than other industrial sectors. It consumes more materials than any other industry, and is a large direct and indirect consumer of energy.

The industry is a very large consumer of materials, and it operates on a growing scale.

At the same time, concerns about the effects on the Earth's environment have been emerging.

Buildings are the greatest producers of harmful gases such as CO2.

For example concrete is one of the most widely used construction materials in the world. However, the production of portland cement, an essential constituent of concrete, leads to the release of significant amount of CO2, a greenhouse gas; one ton of portland cement clinker production is said to creates approximately one ton of CO_2 and other greenhouse gases (GHGs).

Was it always like this? We are living on this planet for million years. But we rarely mentioned about sustainablity. Why? Because up to now we have used different construction types which were much more natural than the materials we use today. Our masters were much more respectful to environment.

According to the World Commission on Environment and Development: sustainability means "Meeting the needs of the present without compromising the ability of the future generations to meet their own needs."

Which means being respectful for the future generation needs. Suleymaniye Mosque as a sustainable structure did minimum damage to environment. During its construction CO_2 gas was not produced. And Architect Sinan achieved not giving any harm to the nature 400 years ago. After 400 years we are arguing how to resume the damage we make to the environment.

Designing for sustainability means accounting in the design the full short-term and long-term consequences of the societal impact. Therefore, durability is the key issue.

After 400 years we can say that the consequence of the societal impact of Suleymaniye Mosque is really impressive.

Durability is the ability to endure. And if we think about 400 years we can understand that this master piece still gives fresh ideas to us about sustainibility.

Sustainability requires that engineers and architect consider a building's "lifecycle" cost extended over the useful lifetime. For Suleymaniye Mosque how can we decide about the useful lifetime? We can only say that it deserves the biggest time period which a building can get.

Light colored concrete walls reduce interior lighting requirements. This helps us to use less energy for the interior areas. And Architect Sinan also got this idea years ago.

The windows for the natural lighting has a great role for sustainability because of reducing the energy. An we also find right answers to this problem at this mosque.

Sustainability is briefly being smart.

And for getting hints of smart thoughts we have to search about the great architect's and engineer's way of thinking. Architect Sinan is one the greatest architects world wide. We can learn lot about his way of using natural light, his way of using wall colors for greater interior effects and minimising energy, his respectful design policy and his way of using natural materials for getting a natural structure.

We are talking about sustainability just for 20 years (after Brutland Report in 1987) but Architect Sinan was building sustainable constructions 400 years ago. This shows that human kind acts in different ways. We give harm to ozene layer and we also give great respect to nature and built marvelous structures with marvelous effect on human soul.

This effect not only gives a great feeling that man kind can solve the problems which he causes and also teaches the techniques of designing natural structures.

3 CONCLUSION

Mimar Sinan's buildings and structures are the foundation of a sustainable future of Turkish Architecture. Here it is aimed to introduce a global view over the Suleyman's Mosque (Suleymaniye Mosque), of Sinan's second perfect product. Suleymaniye Mosque: one of the foundations of a sustainable future following a positive response to the research with this case study, we do share with you the Turkish Architecture's Progress toward sustainable development by providing an overview of the financial, environmental and social preferences of Sinan's second perfect product about mosques.

This paper provides a measurement of the Turkish Architecture of Mimar Sinan's economic, environmental and social preference. It also illustrates the importance of a perfectly constructed buildings and structures in providing sustainable solutions in the construction sector.

As an architecture, we recognize that strong financial performance must continue over the long term in order to maintain a sustainable industry delivering value added products to society.

REFERENCES

Egli, Hans G. (1992), SINAN, An Interpretation, Ege Yayınları, Istanbul.
Fausti P., Pompoli R., Prodi N. (2000-2003). Comparing the Acoustics of Mosques and Byzantine Churces, CAHRISMA Project (EU Contract ICA3-CT-1999-00007, Conservation of the Acoustical Heritage and Revival of Sinan’s Mosques Acoustics – CAHRISMA, 2000-2003).
Goodwin, G. (1971), A History of Ottoman Architecture, Thames and Hudsin Press, London.
Kayili, M. (2005). Acoustic Solutions in Classic Ottoman Architecture, Foundation for Science Technology and Civilization, Publication ID: 4087; United Kingdom, 2005.
Kuban, D. (1997) Sinan’in Sanati ve Selimiye, Turkiye Ekonomik ve Toplumsal Tarih Vakfi, Istanbul.
Kucukerman, E. (1998) Turk Cam Sanayii ve Sisecam, Istanbul’da 500 Yillik Sanayii Yarisi, Turkiye Sisecam Fabrikalari A.S., Istanbul.
Kuran, A. (1986) Mimar Sinan, Hurriyet Vakfi Yayinlari, Istanbul.
Topaktas, L. (2003). Acoustical Properties of Classical Ottoman Mosques Simulation and Measurements, PhD Thesis, Middle East Technical University; Ankara.
http://www.sinanasaygi.com
http://tr.wikipedia.org/wiki/S%C3%BCleymaniye_Camii
http://www.mimarlikmuzesi.org/biyografi.asp?id=10014

Case Study: LEED™ by Design in the School of the Future

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ABSTRACT: The School District of Philadelphia (SDP) and Microsoft partnered to create a unique High School in the urban setting of Philadelphia. This 162,000sf, 800 student high school, which also serves as a community center, opened in September 2006, on time, within an established budget. The learning environment is a bookless, wireless, teaching without walls result. Integrated with this innovative curriculum delivery method is a LEED™ Gold designed building that provides the healthiest space possible to learn and work in. Using the integrated design process and LEED™ green building rating system as our guide, the Owner and design team were able to incorporate the principles of sustainable design into the building within the established budget and schedule.

1 INTRODUCTION

The technologies and strategies employed here are readily applicable to any building type at NO or little additional first cost, assuming a proper budget to start with, and have a tremendous return on investment socially, economically, and environmentally. My role in this project was as the LEED™ manager and responsible for integration of sustainable design throughout the project design process and seeing it through construction.

While sustainable design was a requirement of this project for Microsoft and SDP, it was not the prime driver. Delivering the curriculum in an unconventional methodology and the challenges and opportunities that created, which the building had to accommodate and respond to, was the driver, along with the budget and schedule. LEED™ was an integral part of the process, not an afterthought or add on.

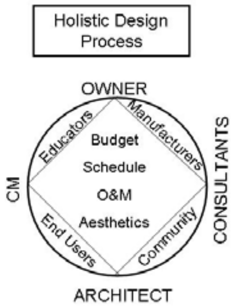

Figure 1.

The integrated design process was essential to successfully incorporating sustainable design on time and within the established budget. While this is not an entirely new process, it is one often less practiced given the nature of fast paced deadlines and entrenched design processes.
Integrated design is as more about a process than the actual selection and design of building components and systems. Getting all the stakeholders to the table early in the process, establishing the goals for the project, and carrying those goals through the entire design and construction process with a method to track and measure the successful incorporation of those goals is the essence of integrated design. Stakeholders include the project design team, owner, and manufacturers to name a few. The adjacent diagram, Figure 1, illustrates the integrated design team and a circular process of communication with open lines between all the players and the typical project concerns that all conversations are weighed against .

2 INTEGRATED DESIGN

The design team must look at a building and its systems holistically to get the full benefits from how they interact to minimize waste and maximize efficiency. This ensures the most cost effective design and lowest operating and maintenance costs. The process by which this happens can vary greatly depending on the type of project, project team, Owner goals, budget, and schedule. The process must, therefore, always be tailored to these project-shaping points. However, as a universal standard of care the LEED™ Green Building Rating System, and similar systems such as BREEAM and Green Globes, provides an excellent framework and checklist for exploring all aspects of a building and the interrelation of the various components. With categories in Sustainable Site Design, Water Conservation, Materials and Resource Conservation, Energy and Atmosphere Conservation, and Indoor Environmental Quality, all major aspects of building design and components are accounted for. The LEED™ checklist is a highly functional tool when used from the programming and goal setting stage through all phases of design and construction. Even if a project is not seeking certification through the US Green Building Council, active use of the checklist and guidelines during design can result in a significantly better performing building with little or no additional first cost by encouraging the right conversations early in the process.

Usually the questions of first cost and payback are always drivers on major decisions affecting the building aesthetics, operation, and maintenance. The School of the Future project was no different. The idea of cost is both a short term and long term question. First cost and maintenance costs must be balanced, yet in the life cycle cost of a building, maintenance accounts for over 50% while construction accounts for only 11% as demonstrated in the lifecycle cost chart below done by Johnson Controls. When you look at the first cost of a building compared to the operation cost of a building, as demonstrated in the 40 year life cycle analysis, it becomes apparent that decisions made in the area with the smallest financial impact, Construction, result in the most significant consequences in the area with the largest financial impact, Operation. All of these decisions are made in an amount of time that is even too small to show on the pie chart, in Design. Design accounts for only 6 to 8% of the 11% initial Construction Cost. In short, all of the decisions that affect the entire Life Cycle Cost of a building are made up front – in the smallest cost percentage of the building. That is why it is so critical to plan for high performance design up front.

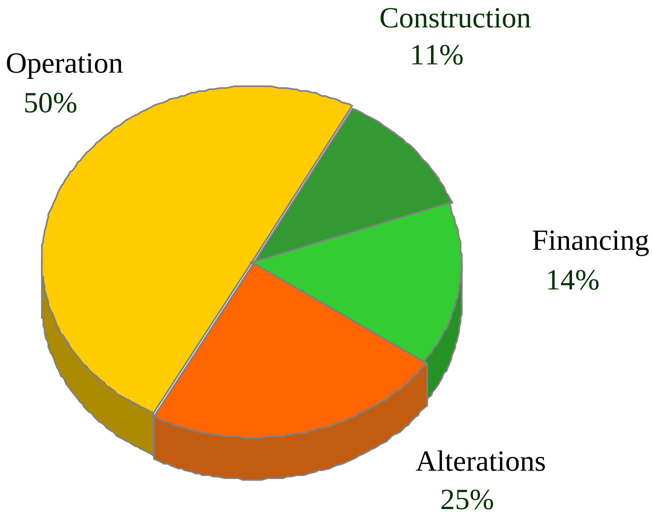

Figure 2. 40 year building life cycle table prepared by Johnson Controls

In the case of the School of the Future, LEED™ was the design guide of choice and the certification level set as a goal was Silver. Using the integrated design process and LEED™ green building rating system as our guide, the Owner and design team were able to integrate the following sustainable design features into the building within their set budget and schedule:

3. LEED™ INTEGRATED SUSTAINABLE DESIGN STRATEGIES

Sustainable Site Design (7 LEED™ credits):

1. Orientation of the building for North/South exposure for optimal daylighting
2. Significantly reduced new parking by working with the adjacent Philadelphia Zoo to use part of their overflow parking instead
3. Energy Star roofing and non-roof surfaces to reduce the heat island effect.
4. Storm water management onsight with an 11,000 sf green roof on auditorium funded by local grant from the Philadelphia Water Department.
5. Pedestrian friendly access via bicycle, light rail, and bus within ¼ mile.
6. Light pollution sensitive exterior and interior building lighting

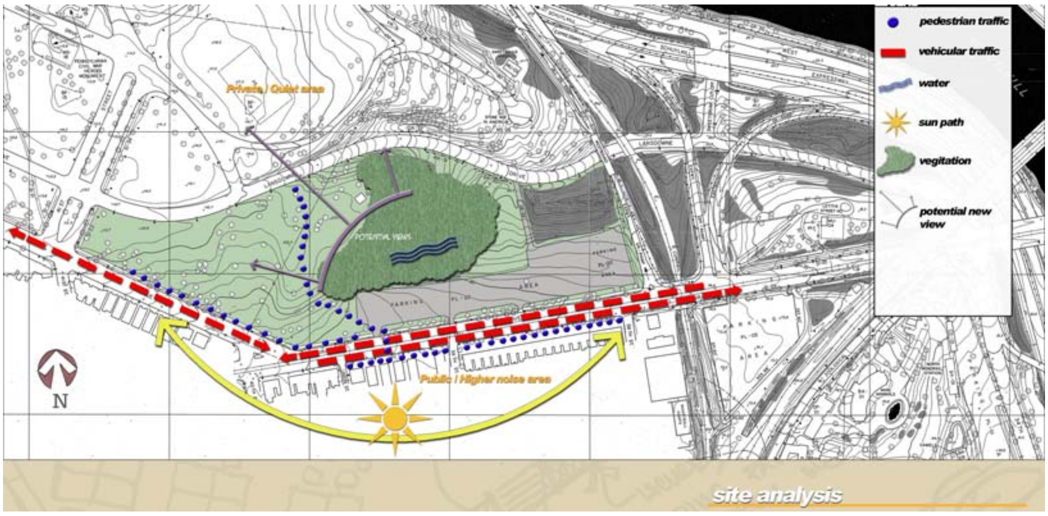

Figure 3. Site Analysis prepared by the Prisco Group

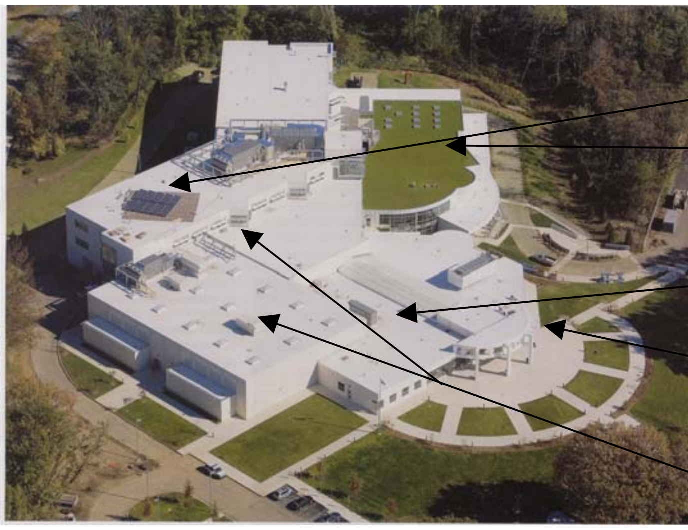

Figure 4. Actual Photo of Completed Building

Figure 5. Diagram of building on-site prepared by the Prisco Group

Water Conservation (5 LEED™ credits) Why do we flush drinking water? Because we always have? Buildings in US use 12% of all potable water.

1. No irrigation system installed for grounds
2. Rain water catchment system installed to flush ALL toilets (56% water savings in the building overall). Partial grant received from local water department for cost of rain water system

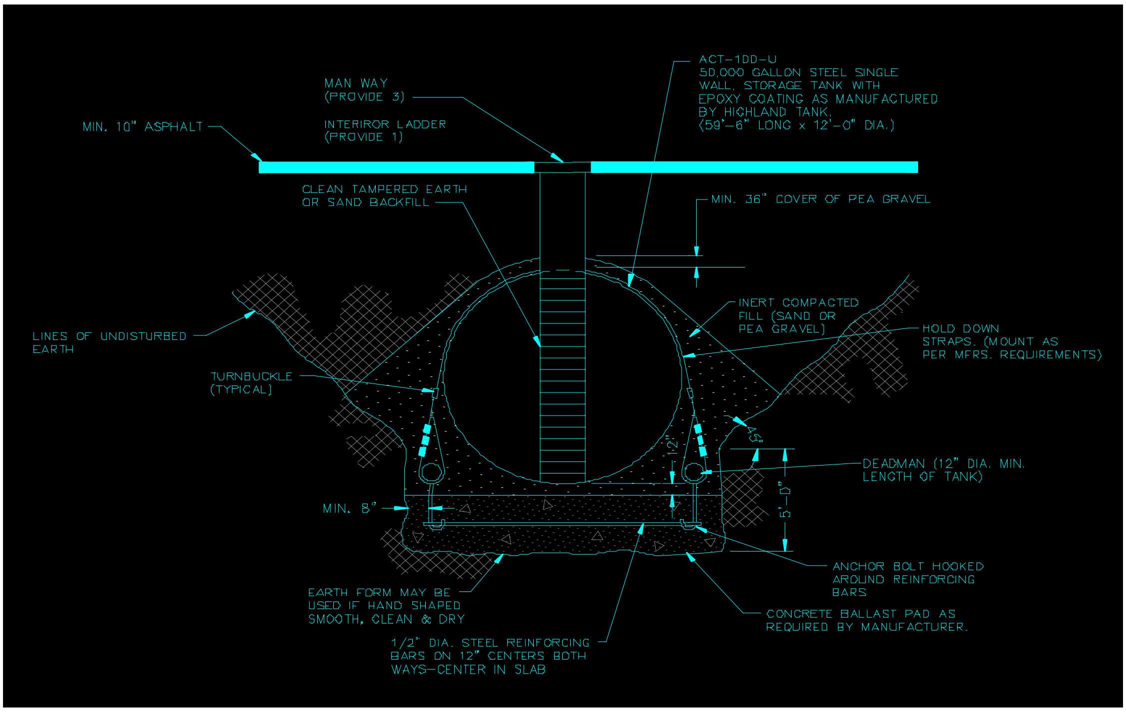

Figure 6. Underground Rainwater Catchment Diagram prepared by The Prisco Group

Total Uses by all Occupants	10,188
Total Daily Volume (gal.)	7,664
Annual Work Days	280
Annual Volume (gal)	2,145,850
Rainwater Catchment Use offset(gal.)	1,069,068
Total Annual Volume Used(gal.)	1,076,782
Total Percentage Reduction	56.07%

Figure 7. Water Use Reduction Summary Table

Energy Conservation (9 LEED™ credits) HVAC & Lighting typically account for 75% of all building electricity consumption. Buildings, in the USA, account for 65% of all energy used.

1. High efficiency mechanical system including thermal storage (see Fig.8), evaporative cooling, extensive heat recovery, dual duct delivery system, $CO2$ monitoring for 49% savings in energy use below ASHRAE 90.1-1999 levels (see Fig. 12).
2. Indirect lighting for reduced footcandle levels
3. Daylighting designed into all public areas (see Fig. 9) classrooms (see Fig. 10), most offices, and gym for reduced artificial lighting requirements
4. Building integrated photovoltaic curtain wall in main atrium (see Fig. 11)
5. Fully Commissioned HVAC, lighting, and building controls

Figure 8. Calmac Thermal Storage Tanks

Figure 9. Kalwall transulecent panel skylight at entry

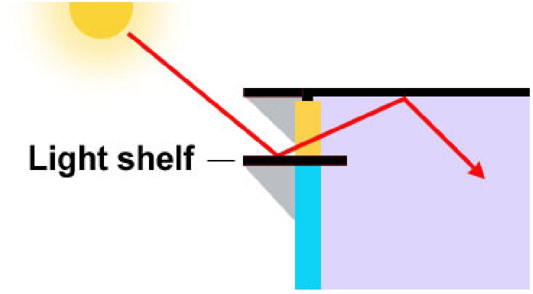

Figure 10. Classroom Daylighting Diagram

Figure 11. Photo of photovoltaic glass designed into atrium curtain wall

Energy Summary by End Use

End Use	Energy Type	Proposed Building Energy [10^3 Btu]	Proposed Building Peak [10^3 Btu/h]	Budget Building Energy [10^3 Btu]	Budget Building Peak [10^3 Btu/h]	Optimized Energy Performance [%]
Lighting - Conditioned	Electricity	1,640,510	498.3	1,977,038	638.6	83.0%
Lighting - Unconditioned	Electricity	36,331		114,636		31.7%
Space Heating	Gas	4,914,000	7,600.0	13,429,000	9,700.0	36.6%
Space Cooling	Electricity	903,776	898.3	849,137	1,079.9	106.4%
Pumps	Electricity	402,847	181.9	320,194	137.2	125.8%
Heat Rejection	Electricity	7,997	18.4	20,304	72.7	39.4%
Fans - Interior Ventilation	Electricity	752,488	371.0	755,068	598.0	99.7%
Service Water Heating	Gas	539,000	30.0	583,000	100.0	92.5%
	TOTAL BUILDING CONSUMPTION	9,196,948		18,048,378		

Energy and Cost Summary by Fuel Type

Type	DEC'' Use [10^3 Btu/hr]	DEC'' Cost [$]	ECB' Use [10^3 Btu/hr]	ECB' Cost [$]	DEC'' / ECB' Energy %	DEC'' / ECB' Cost %
Electricity	3,743,948	$ 100,832	4,036,378	$ 119,569	93%	84%
Natural Gas	5,453,000	$ 97,944	14,012,000	$ 250,975	39%	39%
Other	-	$ -	-		-	-
Total Nonrenewable	9,196,948	$ 198,776	18,048,378	$ 370,544		
Demand Controlled Ventilation	(319,000)	$ (5,693)				
Occupancy Sensors	(210,100)	$ (5,727)				
Renewable					-	-
Total including Renewable	8,667,848	$ 187,356	18,048,378	$ 370,544		
			Percent Savings = (ECB' $ -DEC'' $)/ECB' $ =			49.4%

Figure 12. DOE 2 Energy Model of Base Case & Proposed Building prepared by The Seven Group

Materials and Resouce Conservation (5 LEED™ credits)

1. High recycled content, local materials specified for 20% of all products (see fig. 13)
2. FSC wood used for 54% of wood products in building (see fig. 14)
3. 69% construction waste recycling achieved. (see fig. 15)

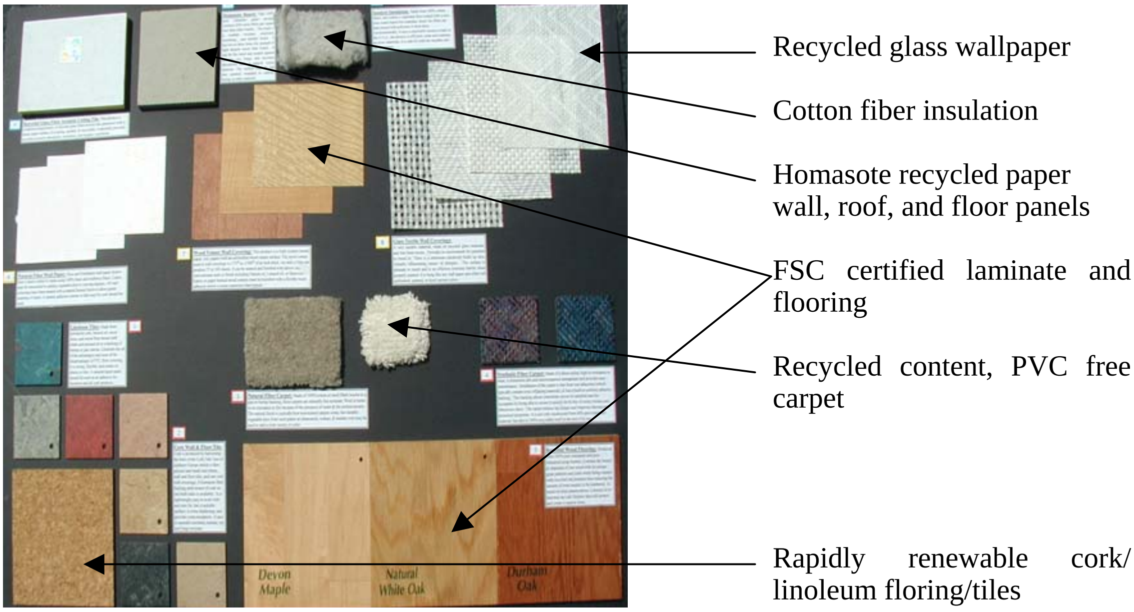

Figure 13. Typical High Recycled Content, Local, Rapidly renewable, sustainably harvested products readily available

Total project cost		$ 18,688,176		
for default total materials cost; OR		$ 8,409,679		
Provide total materials cost (exclude labor, equipment)				
Total cost of all wood-based products		$ 463,035		
Cost of wood-based products as percentage of total materials cost		5.51%		
Product name	**Vendor** OR MANUFACTURER	WOOD COMPONENT COST $	**Certfied Wood %**	**Forest Stewardship Council chain-of-custody certificate number**
Reception Desks	Delaware Valley	$ 1,677	100%	SW-COC-639
Bench, planter and counter	Delaware Valley	3,601	100%	SW-COC-639
Wood benches w/ light pole A13.1	Delaware Valley	179	100%	SW-COC-639
Wood cap at low walls	Delaware Valley	497	100%	SW-COC-639
Wood Base	Delaware Valley	735	100%	SW-COC-639
Wood benches @ 002,253, 333	Delaware Valley	3,109	100%	SW-COC-639
Wood paneling @ Aud. & Stage	Delaware Valley	8,453	0%	N/A
Tall wk. Bench @ 034 F/A13.3	Delaware Valley	294	100%	SW-COC-639
Aud., Stage, Music Room	Flynn Floors	20,475	0%	N/A
Aud., Stage, Music Room Sub Fl	F.S.I./ DJK	7,399	0%	N/A
Gym Floors	Connor Sports Floors	121,394	68%	SW-COC-015
Auditorium Seating	Irwin	4,775	0%	N/A
Wood Doors	Mohawk	161,017	100%	SCS-COC-00517
Rough Carpentry/Miscel.	F.S.I.	46,756	0%	N/A
Casework	LSI	71,610	0%	N/A
Bleachers	Interkal	11,064	0%	N/A
	Product Cost Subtotal	$ 463,035		
			Total value of certified wood products	**$ 253,657**
			value of certified wood products as a percentage of the cost of all wood based building materials	**54.78%**

Figure 14. FSC Certified Product Calculation Chart, prepared by DJ Keating Construction

The quantity diverted materials and means of diversion are explained in the table below.

How and where waste is diverted		Diverted Material, in: ◉ tons ○ cubic yards ○ ______
Clean Fill/Concrete/ Masonry	Winzingers , W. Chestnut, DVR - Phila., PA	276.51
Wood	Academy- Phila., PA	116.6
Paper	Solvay Paper -Solvay, New York	1.87
Drywall	AGRI - Rheinholds, PA	66.15
Metals	SPC Metals- Great Neck, New York	36.41
Wood Chips	Winzingers- Phila., PA	78
Asphalt	Winzingers- Phial., PA	860
	Total quantity of diverted waste	1435.54
	Total quantity of waste	2076.25
	Percentage of waste diverted	**69.14%**

Figure 15. Construction waste recycling chart prepared by Daniel J. Keating Construction

Indoor Environmental Quality (9 LEED™ credits)

1. Photo/motion sensors integrated with lighting, daylight, and HVAC system
2. Increased ventilation: up to 80% fresh air provided.
3. Individual room temperature controls provided with operable windows
4. Daylighting for 75% of all spaces and views for 90% of occupied areas in the building
5. Non-toxic finishes (reduced or eliminated VOC's, formaldehyde, and chlorine) specified.
6. Indoor air quality management plan during construction and pre-occupancy implemented.

Innovative Design (4 LEED™ credits)

1. Rainwater Harvesting for 50% additional reduction over requirement.
2. Building Integrated Photovoltaics in curtain wall. Innovative application of technology.
3. Green Cleaning Policy: District wide plan developed and implemented. (see fig. 16)
4. Building as a teaching tool with sustainable design integrated into curriculum. Comprehensive plan developed and implemented by District. (see fig 17)

Total LEED Credits Attempted: 40

4. CONCLUSION: What is outlined in this report is a summary. There are far more credits with relevant environmental impact not detailed in this report. The full credit summary and more information on LEED™ and the US Green Building Council is available online at www.usgbc.org web site. Additional information on the School of the Future is available at www.microsoft.com/education/sof which addresses the educational and technology integration and innovative curriculum delivery not discussed in this case study, but worthy of investigation itself. Having designed over 6 major projects to the LEED™ Silver standards in the last 5 years,

it has been my experience that LEED™ certified or Silver, or equivalent, projects are readily achievable within a conventional budget and schedule. The most important way to accomplish this is to integrate sustainable design into the conversation and thought process from the outset of any project. As the concern over green house gases continues to rise and local, state, and national entities begin to tackle the issue of carbon neutrality in earnest in the coming century, innovative, cost effective, environmentally responsible design, construction, and operations will become the norm rather than the exception.

Green Cleaning Plan for the High School of the Future

Introduction: Purpose and Content

This Plan has been developed to achieve to goals and realize benefits summarized in the Green Cleaning Policy of the High School of the Future.

The benefits are great:

- Improved learner health
- Increased worker safety
- Increased worker morale and productivity
- Improved indoor air quality

This plan is divided into the following sections and uses attachments such as tables, lists and procedures that may change over time.

Plan Section	Related Attachments
1. Introduction: Purpose and Content	Green Cleaning Policy
2. The Clean Green Team	Clean Green Team Roster
3. Things to Clean	Comprehensive List of Cleaning Requirements and Related Materials, Equipment, Supplies and Procedures and Frequencies
4. The Tools of the Trade	Cleaning Products Cleaning Equipment Cleaning Supplies and Paper Products
5. The How To's	Cleaning Procedures (To Be Developed)
6. Training	Training Program (To Be Developed)
7. Goals and Strategies to Improve	Items for Continuing Improvements (To Be Developed)
8. Timetable and Staffing	Custodial Staff Assignments (To Be Developed)
9. Best Cleaning Management Practices	

Figure 16. Green cleaning plan table of contents, developed by Philadelphia School Improvement Team

Building as a Teaching Tool

Intent

Provide public education focusing on green building strategies and solutions

Requirements and Submittals

Two of the three following elements must be included in an educational program:

- ☐ A comprehensive signage program built into the building spaces to educate the occupants and visitors of the benefits of green buildings. This program may include windows to view energy-saving mechanical equipment or signs to call attention to water conserving landscape features.
- ☑ The development of a manual, guideline, or case study to inform the design of other buildings based on the success of this project. This manual will be made available to USGBC for sharing with other projects.
- ☑ An educational outreach program or guided tour could be developed to focus on sustainable living, using the project as an example.

The proposed requirement is that the Learners develop lesson plans and project learning assignments to supply at least 10 hours per year of classroom instruction around the following four subject areas while integrating the sustainable features of the School of the Future:

Environment & Ecology Standards Subject	Building Features that can be incorporated
4.1 Watersheds and Wetlands* ** These numbers refer to the respective ASEE standards.*	• *Vegetated Green Roof* • *Cistern and Use of Gathered Rain water for Non-Potable uses in the building* • *Pervious Landscaping* • *The "created wetland" which remains in the pre-existing stormwater feature downstream of the site.*
4.2 Renewable and Nonrenewable Resources	• *Recycled Building Materials* • *Photovoltaic Systems* • *Thermal Storage System* • *Recycling Plan*
4.3 Environmental Health	• *High Quality Indoor Air* • *Green Cleaning*
4.8 Humans and the Environment	• *Building Integrated Photovoltaic System* • *Daylighting and Energy Efficient Lighting*

Figure 17. Building as a teaching tool summary developed by School District of Philadelphia

Influence of end-of-life scenarios on the environmental performance of a low-rise residential dwelling

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ABSTRACT: In a life cycle analysis the end-of-life stage is probably the phase more difficult to quantify and therefore subjected to a high level of uncertainties. This is particularly important when the system under analysis has a long life span, which is the case of a building. Due to the high level of uncertainties in the end-of-life stage of a building, usually scenarios are adopted to quantify the inventory data and impacts of the different construction waste materials. In the case of recyclable materials the allocation procedure should be carefully chosen as it can significantly affect the results of the assessment analysis. In this paper a life cycle analysis of a light weight steel dwelling is performed. For the end-of-life stage several scenarios are defined in order to assess the influence of the different options in the overall result of the analysis.

1 INTRODUCTION

During a building life cycle several kinds of material wastes are generated, from the production of the materials to the demolition of the structure. Focussing on the end-of-life of the structure, the material waste resulting from the demolition of the structure can have two major destinies: either the resulting materials can be recycled or reused or the resulting materials are no longer useful and so they are sent to landfill or to incineration. In terms of a life-cycle analysis the first case presents an additional problem to be solved – what to do with the resulting products? Where are they allocated? Current LCA standards do not identify the allocation method to be used and this is usually chosen by the practitioner. However, the choice of the allocation procedure should be carefully made as it can have significant effect on the results of the assessment.

Another question to be solved with the allocation problem of the waste materials concerns the time they are generated. Buildings are usually designed for life spans of 50 to 100 years. This means that the possible benefits gained from the reuse or the recycling of waste materials in the end-of-life of a structure may have a negligible affect on the environmental impacts of concern today.

Therefore it is the purpose of the present paper to illustrate and discuss the questions raised in the previous paragraphs. A life cycle analysis is carried out on a one-family residential dwelling built in a light weight steel frame. In the first part the results of the construction stage are presented. Then various scenarios are considered for the several outcomes of the end-of-life stage. The life cycle analysis is performed with the software for life cycle analysis SimaPro v7.0.

2 DESCRIPTION OF THE CASE STUDY

The analysis is focussed on a one-family dwelling built in Aveiro, Portugal. The house has 2 main floors, with an area of 165 m^2 each, and a smaller top floor with an area of 115 m^2.

Figure 1. Light-weight steel frame

The house is framed with lightweight cold formed steel sections. The external walls consist of an outside layer of Oriented Strand Board (OSB) panels, 11 mm thick, and an inside layer of gypsum boards with a thickness of 15 mm. The gap between the two panels is filled with rock wool 14 mm thick. The internal walls are made of gypsum boards with a thickness of 15 mm and a layer of rock wool with a thickness of 70 mm. The slabs are made of composite panels with a top layer of OSB panels (15 mm), an intermediate layer of rock wool with 70 mm, and a bottom layer of gypsum boards with 13 mm. The rock wool insulation panels completely clad the steel frame ensuring that the house achieves high thermal and acoustic behaviour according to regulatory requirements.

The quantities of the main materials used for the construction of the house are indicated in Table 1.

Table 1. Bill of materials for the light-weight steel house.

Material	Quantities	Unit
Concrete	70680	kg
Steel cold formed	19494	kg
Rock wool	12335	kg
Gypsum plaster board	13208	kg
Oriented strand board	7016	kg
Reinforcement steel	1307	kg

The total cost for the construction of the frame of the house (not including labour work) was about 130.000€. The cost of lightweight steel frame represents approximately 28% of the total cost, 36.000€.

3 LIFE CYCLE ANALYSIS

3.1 *Goal of the study*

The goal of this study is to perform a life cycle analysis of a lightweight steel dwelling, designed for a service life of 50 years, and to determine to what extent a particular choice for the end-of-life stage affects the overall results of the analysis.

3.2 *Functional Unit and system boundary*

The functional unit is a lightweight steel dwelling designed for a service life of 50 years. The boundaries of the system includes all the processes from raw material extraction and material production to the demolition of the structure and final deposition of the construction waste – cradle to grave analysis – Figure 2.

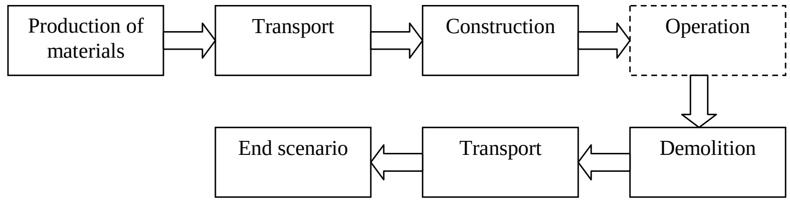


Figure 2. System boundary of the lightweight steel house

Lightweight steel frames need very little maintenance during the service life of the building, and in the operation stage the main impacts came from the use of energy for normal operation of the building (electricity, requirements for heating and cooling, etc). Since the aim of this study is to assess the influence of the end-of-life stage in the overall analysis, the operation stage of the building was not considered in the analysis.

3.3 *Impact assessment method*

The impact assessment method used in this work was the Eco-indicator 99 (Goedkoop et al. 1998). Eco-indicator 99 is a damage oriented method for life cycle assessment. In this method the inventory flows are linked to three damage categories (i) human health, (ii) ecosystem quality and (iii) resources. The end of the environmental analysis leads to the calculation of the total score (endpoint) for the three damage categories. This last step involves the weighting and normalization procedures. The weights are set for three culture perspectives (hierarchist, individualist, egalitarian) based on a panel survey (PRé Consultants, 2001). In this study the egalitarian perspective was used as it is the one that takes a longer time perspective.

3.4 *Production of materials and construction stages*

3.4.1 *Inventory data*

All the inventory data needed for the analysis was supplied by the software SimaPro as this tool includes the full Ecoinvent dataset (2006). The Ecoinvent dataset updated and integrated other databases such as ETH-ESU 96 and BUWAL250 and others. In this work all the material data, apart from cold-formed steel, was obtained from Ecoinvent. Data contained in each dataset includes material and energy requirements and process emissions for the production of 1 kg of the product. Cold-formed steel data was obtained from a north-American database, Franklin 98. In this case, the functional unit was the production of 1000 pounds (= 453.59 kg) of cold-formed steel sheet using electric arc furnace.

The type of road transportation was assumed to be the same for all materials “Road transport by diesel-truck (16 ton); by ton/km; average load 100%”.

3.4.2 *Results*

The construction stage takes into account all the processes to produce the materials and the construction of the house. In Figure 3 the flowchart for this stage is presented. The values presented in each box quantify the contribution of each process to the construction of the house. It can be seen from this picture that the most important process is steel production, with a share of more than 50%.

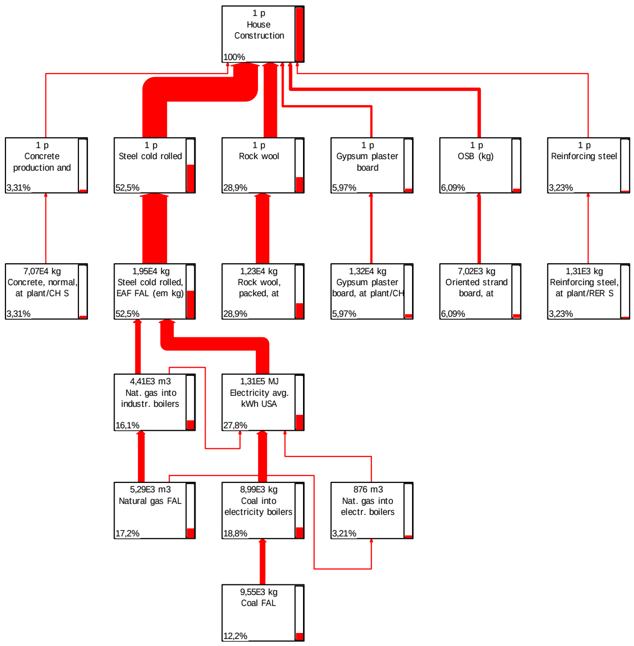


Figure 3. Flowchart for the construction stage

At the endpoint level the result of the analysis, represented in Figure 4, is 5.48 kPt. Steel production, as already seen, is the process with the highest score, 2.88 kPt.

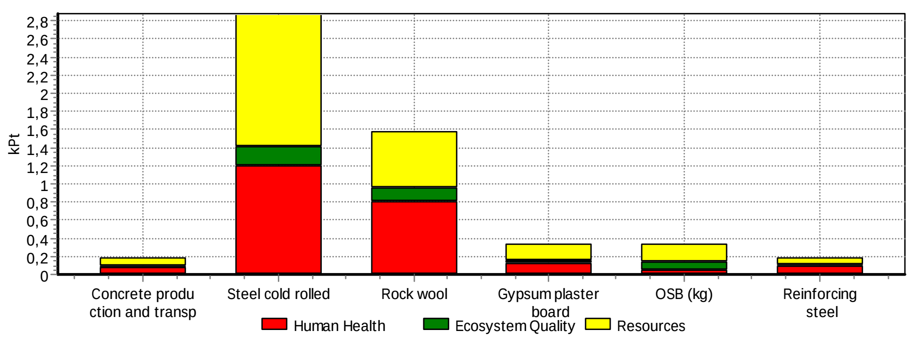
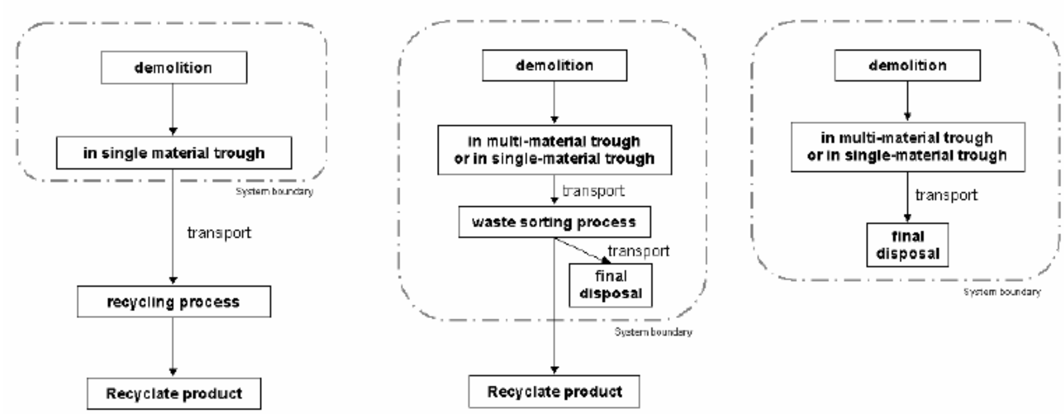


Figure 4. Damage assessment for the construction stage

3.5 *End-of-life stage*

3.5.1 *Definition of the scenarios*

In SimaPro there are three main disposal options for building materials: direct recycling, partial recycling after sorting and direct disposal (land filling or incineration). According to the ecoinvent 2000 methodology no bonus or burden compensation is given for recycled material. The system boundary cuts off the recycling process itself, therefore in the first option (Figure 5a), the material is assumed to be separated from the original construction and transported to recycling. In this case, the system boundary only includes the burdens from dismantling energy consumption and relative Particulate Matter (PM) emissions. The second option (Figure 5b), can be applied to construction materials that cannot be separated at the building site. Thus they are transported to a sorting plant where they are split into fractions and the resulting materials are either sent to recycling or disposal in a landfill or incinerator. Again, the recycled fraction is not included in the system boundary. The inventory data regards dismantling burdens and transport to a sorting plant.



(a) (b) (c)

Figure 5. System boundaries of the three types of disposal options (a) direct recycling; (b) partial recycling; (c) disposal without recycling (adapted from Doka (2003))

In the last option (Figure 5c) the material is separated from the original construction and directly transported to final disposal. The inventory contains dismantling burdens, transport to the final site and final disposal in landfill or incinerator.

These three options for disposal are not directly comparable because the benefits of the recyclable outputs are not taken into account in a standard life cycle analysis. To address this issue, ISO 14041 (1998) states that allocation should be avoided by one of two processes (i) dividing the unit process to be allocated into two or more sub processes and collecting the input and output data related to these sub processes; or (ii) expanding the product system to include the additional functions related to the co-products. A particular solution to the 2nd process is to subtract the additional functions from the product system. This approach is known as "substitution method" or "avoided burden method". This methodology will be applied in the following.

To simplify the problem and to illustrate these issues, given that steel represents over 50% of the environmental burdens, in the following comparisons all end-of-life scenarios will relate exclusively to this material. Concerning steel only, the following three extreme scenarios will be considered: (i) 0% recycling; (ii) 100% recycling; (iii) 100% reuse.

Steel is a material with a very high potential for recycling (up to 100%) and can be recycled over and over again without loosing its characteristics. The output of a recycling process is thus an useful product which can be allocated in the primary material by means of system boundary expansion. In the case of steel, this constitutes the usual default process for steel production (Electric Arc Furnace (EAF) route, that assumes 100% scrap coming from recycling). The benefits of recycling is thus neutral, since this is the default procedure.

Steel is also one of the most durable materials available, which means that very often steel members can be reused following the disassembly of the structure. This completely avoids the production of a new product (steel), all endpoints associated with the EAF production process being deducted from the analysis.

Finally, although a theoretical scenario, sending steel to a landfill would mean that the production of new steel would have to follow a Blast Oxygen Furnace (BOF) production process (obtaining iron ore from mining). This environmental burden thus corresponds to additional endpoints (given by BOF – EAF). Table 2 summarizes the various scenarios.

Table 2. End-of-life scenarios.

Material	Scenario 1	Scenario 2	Scenario 3
Concrete	Sorting+Landfill	Sorting+Landfill	Sorting+Landfill
Cold formed steel	Landfill	Recycling	Reused
Rock wool	Landfill	Landfill	Landfill
Gypsum plaster board	Landfill	Landfill	Landfill
Oriented strand board	Landfill	Landfill	Landfill
Reinforcement steel	Landfill	Landfill	Landfill

3.5.2 *1st Scenario: Landfill*

In the first scenario all the materials are assumed to be sent to landfill. Figure 6 illustrates the flowchart of the life cycle for this scenario.

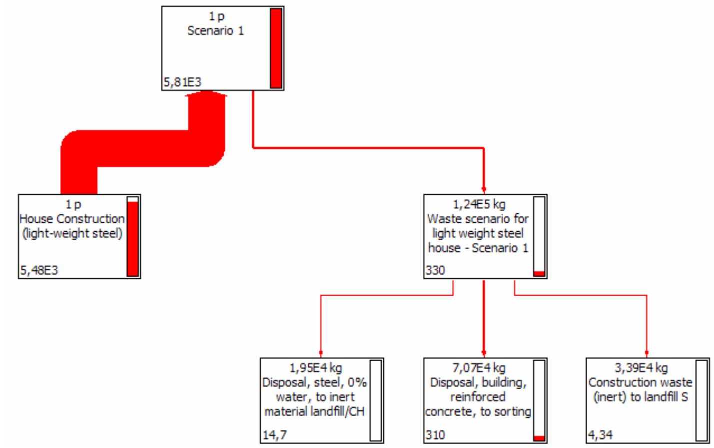


Figure 6. Flowchart of life cycle analysis with end-of-life scenario no. 1

Building material waste is usually inorganic and is treated as an inert material sent to a landfill. Therefore the procedure has little or no emissions and only land use, infrastructure and caterpillar on site are included.

As already seen in paragraph 3.4.2, the construction of the house has an endpoint of 5.48 kPt. The introduction of the end-of-life stage increased the endpoint to 5.81 kPt, corresponding to an additional 6%. The contribution of the latter stage, in this case, is only 330 Pt to the overall result.

For the sake of comparisons between scenarios, considering the theoretical scenario of new production of steel by BOF route, the additional endpoints given by the difference between the BOF route and the EAF route is 1.04 kPt. Therefore, the final result of scenario 1 would be 6.85 kPt.

3.5.3 *2nd Scenario: Recycling*

In this scenario all the previous disposal options were kept for all the materials except cold-formed steel. The latter was assumed to be sent for recycling. Figure 7 illustrates the flowchart of the life cycle for this scenario.

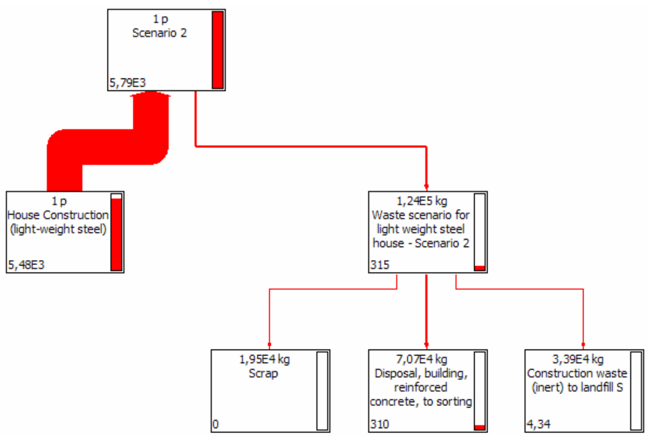


Figure 7. Flowchart of life cycle analysis with end-of-life scenario no. 2

In this scenario the benefits gained from the processing of steel recycling where already taken into consideration in the production of steel through the EAF route. Thus in end-of-life scenario, scrap has simply no burdens. The introduction of the end-of-life stage, in this case, increased the endpoint to 5.79 kPt (an increase of approximately 5.7% due to demolition and transport). The contribution of the last stage is, in this case, of 315 Pt.

3.5.4 *3rd Scenario: Reuse*

The last scenario is similar to the previous one, apart from the assumed waste option for cold-formed steel. In this scenario the steel structure is dismountable and 100% of steel is assumed to be reused. Figure 8 illustrates the flowchart of the life cycle for this scenario.

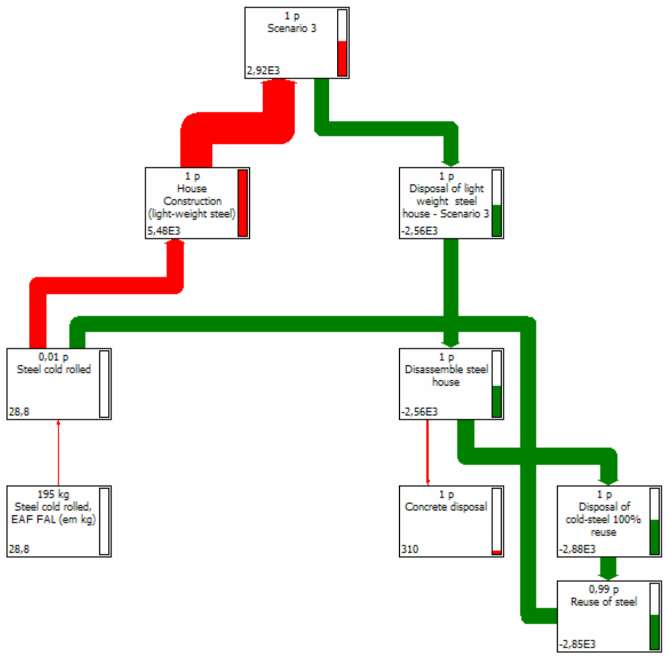


Figure 8. Flowchart of life cycle analysis with end-of-life scenario no. 3

SimaPro allows to define a loop between the steel that is necessary for the initial construction and steel that is going to be reused in a future construction. Therefore, the endpoint for this analysis is 2.92 kPt and the contribution from the end-of-life stage is -2.56 kPt.

3.5.5 *Comparison of scenarios*

The following figures present the results for the life cycle analysis for the various scenarios.

Figure 9 presents the same results in terms of damage categories and Figure 10 presents the results in a single value (endpoint).

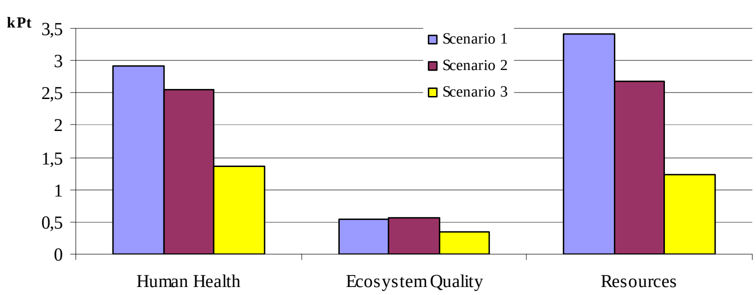


Figure 9. Damage assessment

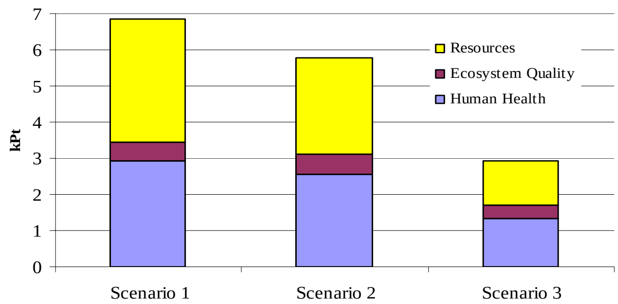


Figure 10. Damage assessment – Total endpoints

The same conclusion can be taken from both figures, end-of-life scenario 3 gives more benefit to the overall analysis than scenarios 1 and 2, and end-of-life scenario 2 is more beneficial than scenario 1.

4 CONCLUDING REMARKS

In this paper a life cycle analysis of a lightweight steel dwelling was performed. For the end-of-life stage three scenarios were chosen showing the influence of the choice in the overall analysis.

Recycling has a detrimental effect of 5.7%. Naturally, compared with the value for recycling, reuse has a beneficial impact of about 49.6%. However, the second question remain open, concerning crediting today the benefits of recycling or reuse of a process that is going to take place in 50 years. In long time periods the level of uncertainties is very high and it is very difficult to predict which are the major environmental impacts in the future as it is difficult to say that the benefits of recycling in the future are benefit to the environmental impacts of today. Nevertheless the use of recyclable materials and design for deconstruction should be promoted thus the integration of time in life cycle analysis is an issue that deserves more research.

ACKNOWLEDGMENTS

Financial support from the Portuguese Ministry of Science and Higher Education under contract grant from FCT (Grant No. SFRH/BD/18801/2004) for Helena Gervásio is gratefully acknowledged.

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REFERENCES

Doka G. 2003. Life cycle inventories of waste treatment services. *Ecoinvent report No. 3*, Swiss Centre for Life Cycle Inventories. Dübendorf.

Ecoinvent Centre. 2004. Ecoinvent data v1.3. Final reports ecoinvent 2000 No. 1-15. Swiss Centre for Life Cycle Inventories. Dübendorf. Retrived from: www.ecoinvent.ch.

Goedkoop M., Hofstetter P., Müller-Wenk R. and Spriensma R. 1998. The Eco-Indicator 98 Explained. *In: Int. J. LCA*, **3**(6), pp. 352-360.

ISO. 1998. Environmental Management – Life-cycle Assessment – Goal and Scope Definition and Inventory Analysis, International Standard 14041.

PRé Consultants B.V. 2001. The eco-indicator 99. A damage oriented method for life cycle impact assessment. Methodology report.

The SHE project: Sustainable Housing in Europe. Social housing coops' best practices for sustainable communities

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ABSTRACT: The pressure to set out strategies for sustainable building to reduce CO_2 emissions and energy consumption is increasing. The social housing cooperatives, managers of a large segment of the housing stock and expression of inhabitants' needs, are important actors for sustainability. This area has been largely ignored in current development activities, that often do not follow an integrated and people centred approach.

This paper presents the first results of an ongoing EU co-funded project, where social housing cooperatives have partnered with scientific and technical organisations to demonstrate the feasibility of sustainable housing on a daily practice.

The 8 case studies in Denmark, France, Italy and Portugal illustrate the potential and the obstacles of applying sustainable solutions.

The main project outcomes:

-Recommendations for social housing organisations, for clarifying the responsibilities of all participants involved and the procedures for the management and design process;

- A dwelling manual for each SHE pilot project for reinforcing environmental awareness of inhabitants in the use and maintenance of the dwellings;

-The global life cycle cost methodology, for highlighting social and economical advantages of sustainable housing.

1 INTRODUCTION

The SHE "Sustainable Housing in Europe" R&D European project, is a five-year European demonstration project funded within the 5th FP - Energy, Environment and Sustainable Development, Key Action 4 – Cities of the Future and Cultural Heritage (March 2003 – February 2008). It aims, as major objective, to send a clear message to all urban stakeholders and citizens that today moving towards an everyday practice of sustainability in newer housing estates, involving all stakeholders and especially the final users in the building process, is possible and necessary. The SHE commitment is to demonstrate that the application of basic sustainable principles in the daily practice is not a utopia of the next millennium, but a commitment that should be attended by everybody and that is worthwhile to everybody.

. At the end of the project, thanks to the continuous involvement and interaction of different stakeholders (housing cooperatives, technicians, universities, providers, professionals, public bodies, etc.), sustainable dwellings for about 600 families will be designed, built and monitored in Italy, Denmark, France and Portugal. The new methodology and the guidelines developed by the SHE consortium will demonstrate the replicability of sustainable housing in different climate and situations, such as those of the European Union.

Since 2003, eight social housing organisations together with a team of well-experienced experts, coordinated by the Federabitazione Europe (Italian housing co-operatives federation), are working to develop an integrated approach on new urban areas, promoting the inclusion of sustainable urban management in political agenda and policies at national, regional and local levels in 4 countries. The partners forming the SHE consortium are social housing organizations and a group of experts, under the coordination of Federabitazione Europe - Confcooperative, a national housing co-operatives federation.

The SHE project is innovative not because of new products or technologies, but because of its methodology and aim. The involvement of cooperatives, end-users, designers, public bodies, producers, etc. from the beginning of the project, is the most important means for moving towards a common practice of sustainable housing. The idea is not to set very high level standards for the dwellings that would only be applied by a minority, but to define minimum standards, with good levels of energy and water savings and with affordable costs that can be adopted by everybody.

There is already an important number of technologies, systems and materials for sustainable building projects but the real problem is to introduce them into the common practice, taking into account the social and environmental conditions of the building site and activating a cultural process for involving and convincing all the stakeholders of the necessity of a sustainable built environment.

2 THE SHE APPROACH

The SHE project wants to ensure to each main subject a scientific advisory. A team of experts supplies the necessary scientific support to implement sustainability in each pilot project.
The topics of interest, the so called Horizontal Activities, are of great importance for the publication of the new methodology and guidelines.

2.1 *Participation Process*

The participation process is an essential part of sustainable construction projects' management. It consists in the whole range of actions aiming at making the different stakeholders take part and/or influence the decision making process.

The participation process includes different types of actions with different interaction and influence levels: from the information to the cooperation level. The level and intensity of participatory actions and their concrete influence on the decisions represent a significant indicator of the projects' social sustainability level.

The process of participation implies the set up of a dialogue between the different stakeholders since the brief writing stage. The dialogue fosters the implementation of higher quality projects responding to both end-users' needs and expectations as well as to community's interests. It also contributes to the end-users' change of behaviour. The dialogue with the future end-users helps achieving dwellings' optimal use and long term performance as well as an appropriate management of buildings.

2.2 *Social and economic aspects*

Sustainability is a shared responsibility. Co-operation and partnership with different level organizations are crucial. The objective is to structure and organise a common platform to carry out inquires for evaluating the values and attitude of the tenants towards the environmental issues. For each pilot project a specific model, the SET SHE model, regarding the shared global cost for each project and for different types of actors will be developed.

This innovative Life Cycle Cost, based on the OLCC, approach is a crucial tool for evaluating the importance of sustainable housing benefits and to convince the national and local governments to provide incentives for sustainable housing based on its social and economical advantages. It includes externalities and induced impacts making the project "shared" between different actors. *Externalities* include environmental and social impacts, which do not have a market value. *Induced impacts* regard the indirect impact of a project.

The objective is to work out and apply a new specific methodology using both economic and social impacts as assessment tools.

2.3 *Site Analysis, building and landscape design*

The principal aim of a site analysis is to highlight a design method to guide the eco-sustainable design process of the different SHE projects. It represents the first essential step which provides basic information to define project sustainable targets. From the site analysis it is possible to get a clear overview of the existing situation in which the project stands, both in terms of potentialities offered by the site and problems to solve (even looking to the neighbourhood scale).

The macro activities that should be performed by each design are the site analyses, the definition of specific design targets and the selection and control of the different solutions.

2.4 *LCA procedures, safe materials and technologies*

The principal aim is to provide guidelines and recommendations concerning the choice of sustainable building materials, components and maintenance or finishing products.

The following Guidelines are provided to enable design teams to orient their choices and clearly focus the problem, considering that in a sustainable approach materials have to be evaluated comprehensively, taking into account the implications related to their overall life: from the production to the dismissing.

2.5 *Water, ground and underground management cycle*

The aim is to achieve large conservations on the water consumption by using well-known techniques, materials and components – perhaps used in another and less familiar way. Of course, without minimizing the comfort of the housings noticeably.

The purpose is to limit the interference in the natural water cycle as much as possible. In practice, this takes place partly by limiting the quantity of water, which is pumped for consumption, partly by retransferring the optimum quantity of rainwater to the water cycle through local percolation and industrial water

2.6 *Waste management cycle*

The “Waste Management” recommendations deal with “prevent – separate – recycle” of waste in connection with the construction and operation of housing.

Construction waste is the subject with most focus, (however, household waste is not less interesting) as with our increasing purchasing power, experience a still increasing quantity of goods flowing through the modern households. Construction waste emerges the year in which the housings are built, whereas the household waste arises for the next 100 years during the operation of the housings.

2.7 *Energy management cycle*

The main objective is to reduce CO_2 emissions. For each demonstration project the eco-management for energy is encouraged. The guidelines are meant to develop and finalise ventilation and heating system designs, to explore the feasibility of mixed mode or natural ventilation approach, to consider thermal storage options, to select exterior wall systems and insulation appropriate for the local climate, to reduce the needs for cooling using passive cooling systems and to use active and passive solar systems.

Important preliminary targets for energy performances have been set and, as for the simulations already done, they have even been over-passed by many of the SHE pilot projects.

2.8 *Day-lighting and acoustic issues*

The objective of this topic is the satisfaction of visual and acoustic comfort requirements inside the buildings. It is important to promote day lighting instead of artificial lighting, sun shading devices, correct fenestration and the use of innovative solutions and special materials for day lighting applications.

Specific information have been provided for the noise control, both at neighbourhood and building scale, through careful planning of the building.

2.9 *Energy and environmental simulation and monitoring*

The main objective of simulation and monitoring is to measure and quantify the actual performance of the buildings, comparing it with the theoretical expectations based in the strategies adopted in each project.

The information gathered through the monitoring activities will be used to examine the efficiency of the choices adopted in the planning phase, and to increase the know-how and awareness of the cooperatives regarding the use of innovative tools to be applied in future projects.

Table 1: Targets set up for saving natural resources and results of the simulations (compared with local regulations or with past experiences)

Saving of natural resources (average of the 8 SHE pilot projects)		
	Target	Simulation
Energy saving for heating	30 %	40 %
Energy saving for cooling	100 %	100%
Energy saving for lighting	20 %	20%
Water savings in the building, including rain water recover	40 %	40%
Reduction of the use of primary raw materials	25 %	30%
Reduction of construction related waste	45 %	60%
Recycling of urban waste during the use of the buildings	35 %	35%
Reduction of the best practice life cost of the construction process	65 %	55%

To conclude, it is important to note the difficulty of synthesizing and simplifying some complex HA topics into practical documents. Scientific partners and social housing organisations have therefore discussed how to transfer the original HA recommendations into more feasible recommendations. As the challenge is to move from extraordinary to the ordinary, we have tried to avoid unrealistic targets and documents, that are too long or academic and therefore not practical tools for housing organisations.

3 THE IMPORTANCE OF COMMUNICATION

Great attention has been given to the dissemination activities which have been carried out according to the SHE principle that dissemination is not only spreading information, but involving and convincing. The SHE consortium has been engaged in activities to create a broader consensus on sustainable housing and to stimulate the participation of the decision-makers and the main actors of urban management. More levels of communication were used in order to create a new vision towards sustainable urban development and to prepare the ground for acceptance of sustainable concepts. At all the events, there is an increasing interest in sustainability topics and high expectations from representatives of various national stakeholders.

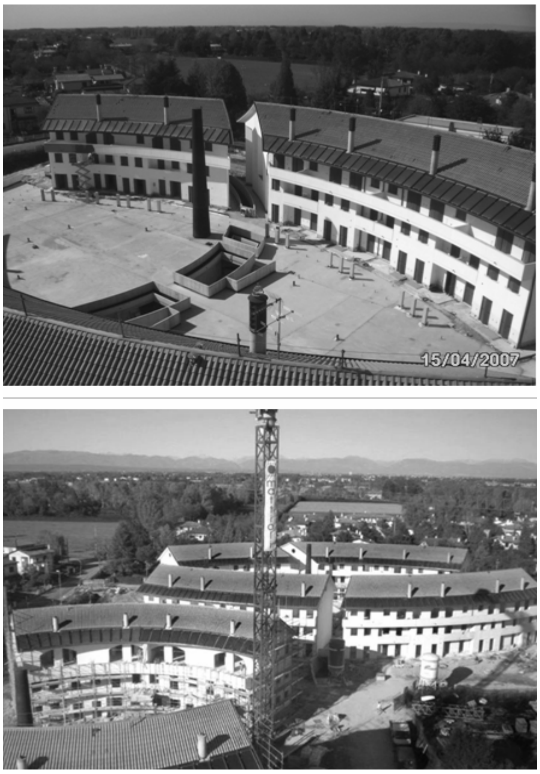
The social housing organisations are strategic actors for urban sustainable development and therefore their commitment contribute to the change of urban planning management. Many municipal land planners have understood that citizens ask to live in a sustainable way. The importance given to the bottom-up demand is innate in the cooperatives of many countries.

The specific aims of the SHE dissemination activity are:

- To provide interactive and targeted information on the project, putting in evidence the relevant features, the problems encountered and the measures for overcoming them;
- To ensure a widespread dissemination of knowledge. Adoption and exploitation of the successful approaches and techniques used in the SHE project also through the usual networks of the social housing organisation;
- To enable key decision-makers to adopt these approaches and techniques;
- To disseminate relevant results to the new members countries;
- To spread the results to the different stakeholders involved, to the members of candidate countries through distribution of newsletter, booklet, press releases, book, mobile exhibitions;
- To publish and update a project dedicated web site: www.she.coop

4 THE SHE PILOT PROJECTS

According to the SHE approach, the demonstration projects are now under construction or already built. Each of the 8 pilot projects provides concrete examples sustainability integration by means of long-term management of land, water, waste, energy and natural resources in social housing, and of integrating close participation of citizens in all the decision-making phases of urban management.

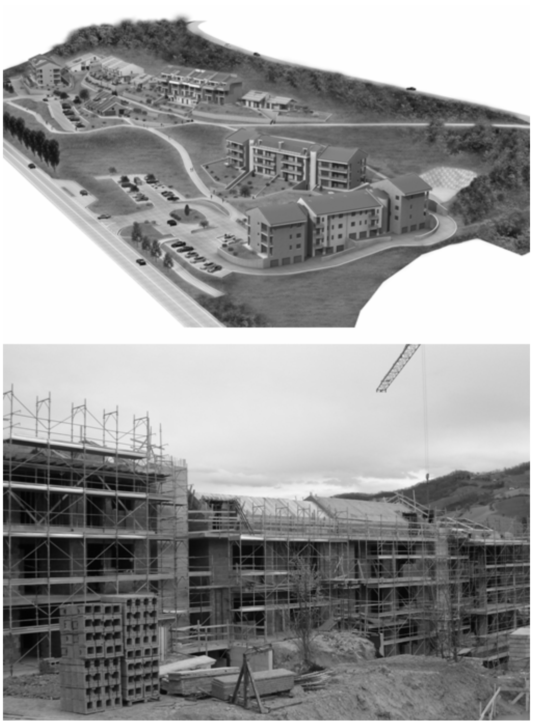


The Preganziol project – Treviso (IT)
Social Housing organization: COIPES
70 eco-dwellings
Construction: November 2005 / March 2007

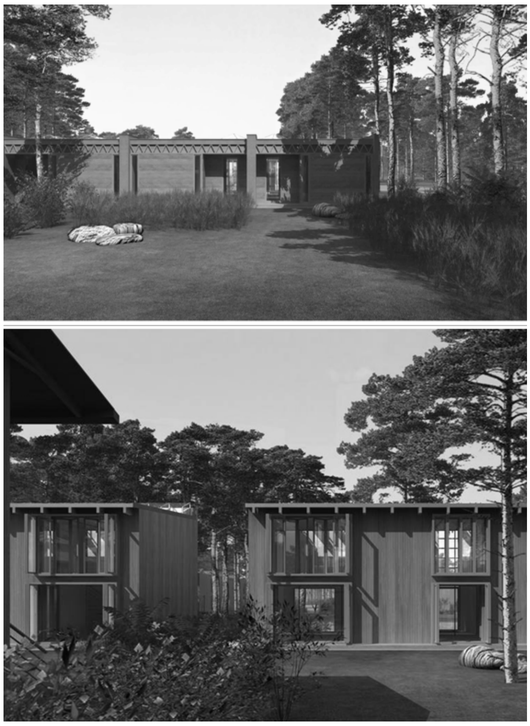
The Villa Fastiggi project – Pesaro (IT)
Social Housing organization: COPES
130 eco-dwellings
Construction: November 2005 / May 2007

The Mazzano project – Brescia (IT)
Social Housing organization: CONSEDI
40 eco-dwellings
Construction: May 2006 / December 2007

The Ozzano project – Bologna (IT)
Social Housing organization: COPALC
12 eco-dwellings
Construction: May 2005 / December 2006

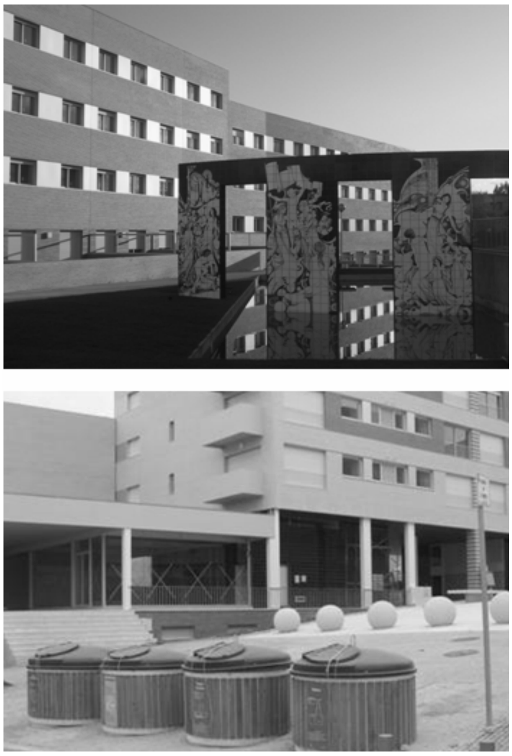


The Teramo project – Teramo (IT)
Social Housing organization: CCICASA
60 eco-dwellings
Construction: April 2006 / September 2007



The Lystrup project – Aarhus (DK)
Social Housing organization: RINGGAARDEN
130 eco-dwellings
Construction: January 2007 / November 2007

The Burgoin-Jallieu project – Grenoble (FR)
Social Housing organization: OPAC38
61 eco-dwellings
Construction: March 2003 / March 2004



The Matosinhos project – Porto (PT)
Social Housing organization: NORBICETA
101 eco-dwellings
Construction: December 2004 / February 2007

5 REPLICATION POTENTIAL AND FIRST IMPACTS

The replication potential of SHE is very high and the first results and impacts on the building sector and social housing practices are already visible.

The SHE project has contributed to boost keys stakeholders to understand that it is time for action, and the social housing movement has demonstrated that cooperatives are almost a perfect means for understanding what sustainable living is and how it is possible to change behaviors and attitudes. Social housing providers are considered as key actors for the generation of dynamic partnerships, linking the creativity and intensity of a wide range of actors.

The SHE partners have recently promoted in each country professional training, dissemination and training actions for informing the managers of the housing coops and the end-users about the use of renewable energies, bioclimatic approaches, ecological materials, etc.

In Italy, Federabitazione has recently created an innovative network of social housing coops for providing practical energy and environmental recommendations and quality procedures for the building process (design, construction, use and maintenance).

In France, OPAC38's board decided to develop its own Agenda 21 for promoting the inclusion of sustainable concept in the daily practice of OPAC38.

Similar results have been reached in Portugal and Denmark and it is important to note that the SHE buildings have managed to create a growing interest of the professional actors: many architects and students are visiting the construction site, asking for details about the technical and non-technical issues of the project, discussing thesis on the new trend of sustainable architecture and the SHE approach. Delegations from many countries have come to Italy to visit the building sites: delegations from Singapore, Poland, Australia, etc.

The SHE project is a great inspiration for other housing associations, private, municipal and international organizations, i.e. the participation at the United Nations HABITAT meeting of Nanning (China) as one of the best European projects on urban sustainable development.

In the municipalities where the pilot projects are situated there is a “domino effect”: more and more the local actors are asking the SHE partners to be engaged in new housing projects or to give advice to reinforce professional skills, impose high demands for the energy and environmental quality in housing projects.
On February 2007 the SHE project was awarded with the prize of the Sustainable Energy Europe Campaign 2005-2008 (Fig. 2) – A European Campaign to raise awareness and change the landscape of energy (www.sustenergy.org), which is an important recognition and also confirms the key role of social housing providers in raising the awareness of decision-makers at local, regional, national and European level, spreading best-practice, ensuring a strong level of public awareness, stimulating the growth of private investments in sustainable technologies.

SHE won the section “public-private partnership” with the following motivation of the Jury:

“SHE represents a shining example of a public-private partnership were social housing cooperatives on a local, regional and European level have partnered with building companies, scientific institutions and technical organizations to demonstrate the feasibility of sustainable housing and communities. SHE focuses on raising awareness among end-users and wants to improve the lives of citizens by offering healthy and sustainable environments.
The partnership is demonstrating an integrated approach to the development and construction of sustainable housing by making the extraordinary ordinary. By the end of the project, 600 families in Denmark, France, Italy and Portugal will be living in sustainable dwellings.
SHE will develop best-practices guidelines so that sustainable dwellings can be replicated by others.”

Figure 2: SHE awarded by the Sustainable Energy Campaign Prize of the European Commission

6 CONCLUSION

The SHE team has made a considerable pressure on the key stakeholders and the activities carried out have not been limited in time or place. The actions have generated further progress and achievements both for the projects themselves and for the local and national policy.

The social housing cooperatives have demonstrated to be almost a perfect means for raising the awareness towards sustainable living and for changing the lifestyles. They are also key actors for the generation of dynamic partnerships, linking the creativity and intensity of a wide range of actors, injecting energy into the national dialogue on sustainable development.

At the beginning of the SHE project, in 2003, the decision to make an effort to lower the major barriers was a big challenge. In all the countries involved, the efforts of the national governments were almost inexistent or fragmented, the process of mainstreaming sustainable practices was very slow and the key EU documents, as the *Thematic Strategy on the Urban Environment* or *Energy Performance of Buildings Directive,* were not published yet.

In light of this, it is easy to understand that the SHE philosophy was considered a very long-term vision, or even an illusion of some utopist cooperators.

However, in the last years, due to the increased focus on climate change, natural resources and energy prices, we have experienced a strong increase of interest. New technical knowledge, products, projects and local regulations are coming out and actors of the building sector are realizing that they can actually have an impact.

The different SHE teams have acted as critical friends with the local governments and as ambassadors for sustainable housing development and we can affirm that the SHE project contribution was to go from a “non-culture” to a culture of sustainability.

Natural illumination availability in Ponte da Pedra apartment block – a case study

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ABSTRACT: This paper presents the results of the in-situ measurements of the natural illumination availability in the Ponte da Pedra apartments block. These measurements were carried out in order to meet the SHE (Sustainable Housing in Europe) project requirements. This paper also presents a comparative analysis of the natural illumination environmental conditions of one of the apartments in this building, by using two simulation tools to predict natural illumination availability: "Ecotect" and "Desktop Radiance". The results obtained with these tools were also compared with the "in situ" measurements, in order to show that simple and user-friendly software tools can be a good basis to evaluate the real natural illumination conditions in the practise of a building project.

1 INTRODUCTION

Daylight is playing a significant role in achieving quality of life and comfort in buildings. There are ample evidence that access to windows affect mood motivation and productivity at work, through reduced fatigue and stress (Tabet & Shelley, 2003). Daylight can also provide economic benefits by dimming down or switching off electric lights. Recognized such importance, an urbanization located in Ponte da Pedra, Porto, implemented some strategies regarding the improvement of natural illumination conditions.

Some measurements were carried out in order to characterize the "in situ" daylight availability. This characterization was based on a quantitative evaluation of the natural illumination conditions, through the assessment of the Daylight Factor (DF), calculated considering the simultaneously measured values of the interior and exterior illuminance levels.

2 METHODOLOGY

For this study, some "in situ" measurements were taken in order to evaluate the daylight availability of the apartments block under study. The measurements were carried out on winter days, in different apartments at different heights and for three types of rooms (kitchens, bedrooms and living rooms) with different geometries and window-openings, under conditions similar to an overcast sky (Batsford, 1992). The "in situ" values were also compared with those obtained with two simulation tools in order to assess which of them lead to better results.

The parameter considered for this study was the Daylight Factor calculated through an alternative method (Santos, 2001) by the following expression (1):

$$DF(\%) = \frac{\sum E\,\text{int}}{\sum Eext} \times 0.396 \times 100 \quad (1)$$

Where Eint = internal horizontal illuminance; Evext = External Horizontal illuminance.

This expression is used when the exterior sensor illuminance is placed in a vertical line. For the calculation of the Daylight Factor, there were needed two illuminance sensors, as it can be seen in Figure 1, one placed inside the room and the other placed on the centre of the window glass. On the outside of the window, an obstruction element was placed at the bottom of the window (see Figure 1) in order to avoid that the reflected light by the ground hit the sensor.

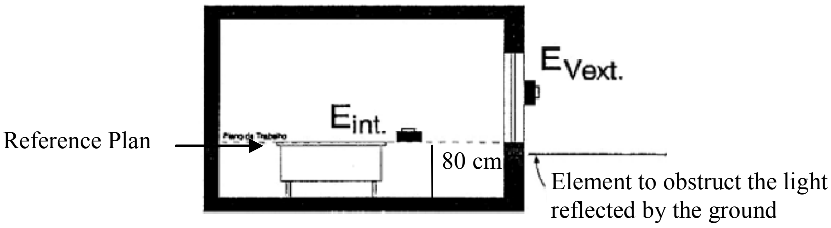


Figure 1 – Method of measurement of the illuminance levels

The illuminance levels in the rooms were measured, around 12:00 h (solar time), in a horizontal level, 80 cm above the floor, on a square grid with points equally spaced of 50 cm.

3 DESCRIPTION OF THE CASE STUDY

The measurements campaign, in order to evaluate the daylight availability inside the building, was carried out in several apartments, in lot number 8 (see Figure 2 below), at different levels. This building is an apartment block located in Ponte da Pedra (latitude 41.17 and longitude -8.37). The building is located in an area without significant obstructions.

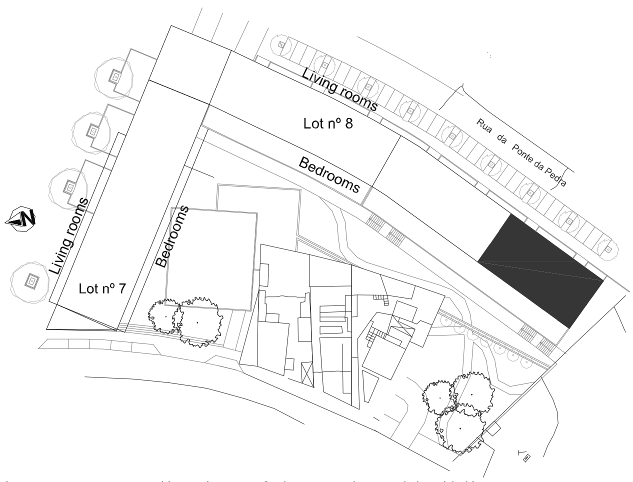
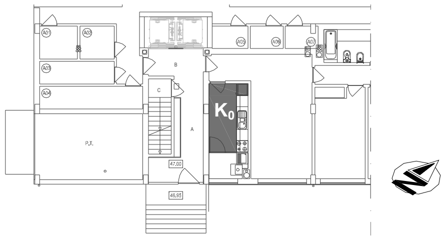
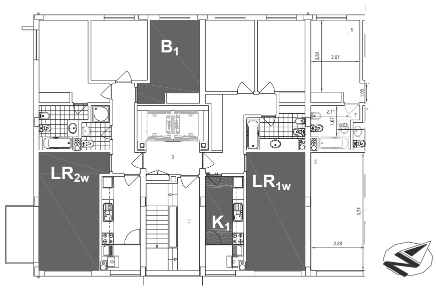


Figure 2 – Localization of the analyzed building

According to the methodology defined by the SHE project, the measurements were carried out in three different rooms (bedrooms, living rooms and kitchens) for various types of windows. The analyzed compartments are identified and shown in Figure 3.



K0 – Kitchen on the ground floor, south-west oriented

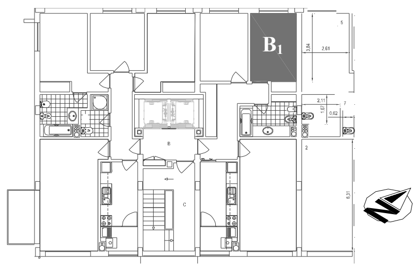


K1 – Kitchen on the 1st floor, south-west oriented

B1 – Bedroom on the 1st floor, south-east oriented

LR1w – Living Room with two windows, on the 1st floor, south-west oriented

LR2w – Living Room with one Window, on the 1st floor, south-west oriented



B3 – Bedroom on the 3rd floor, north-east oriented

Figure 3 – Identification of the selected rooms used for the daylight availability assessment

Tables 1 and 2 show a list of the characteristics of the different indoor surfaces and windows.

Table 1 – Reflectance properties of the indoor surfaces (Santos, 2001)

Interior Surface	Colour	Texture	Condition	Reflectance (%)
Wall (bedroom)	Clear - yellow	wall plaster smooth	clean	76
Wall (living room)	Clear - yellow	wall plaster smooth	clean	76
Wall (kitchen)	White	glazed	clean	60
Ceilings (bedroom)	White	wall plaster smooth	clean	86
Ceilings (living room)	White	wall plaster smooth	clean	86
Ceilings (kitchen)	White	wall plaster smooth	clean	86
Floor (bedroom)	Clear - brown	Wood polished	clean	30
Floor (living room)	Clear - brown	Wood polished	clean	30
Floor (kitchens)	Dark - grey	Wood polished	clean	10
Furniture and door (bedrooms)	Clear - brown	Wood polished	clean	48
Furniture (living room)	Yellowish-brown	Wood polished	clean	48
Furniture (kitchen)	Dark - Blue	Vinyl smooth	clean	15

Table 2 - Properties of the Windows Openings (Saint Gobain, 2000)

Interior Surface	Colour	Texture	Condition	Transmittance (%)	Sc *
Double Glass (bedroom)	transparent	smooth	clean	81	0.87
Double Glass (living room)	transparent	smooth	clean	81	0.87
Double Glass (kitchen)	transparent	smooth	clean	81	0.87
Simple Glass (kitchen)	transparent	smooth	clean	90	0.98

*Sc- Shading Coefficient

4 REFERENCE VALUES

Table 3 shows a list of the recommended values of the Daylight Factor, for the three types of rooms studied (kitchens, bedrooms and living rooms).

Table 3- Recommended values of the Daylight Factor

Rooms	DF (%)*
Bedrooms	≥ 0.5 % at 3/4 of the compartment length
kitchens	≥ 2 % at 1/2 of the compartment length
Living rooms	≥ 1 % at 1/2 of the compartment length

*Values recommend by the Commission of the European Communities

5 SIMULATION TOOLS

For the comparative analysis, two of the most well-known simulation tools of natural illumination availability were selected: “Ecotect” and “Desktop Radiance”. The real conditions were recreated in these programmes and simulated results were produced in order to be compared with the real ones.

5.1 “Ecotect”

The original “Ecotect” software was written and presented in a PhD thesis by Dr. Andrew Marsh at the School of Architecture and Fine Arts at The University of Western Australia. Since then, the software has undergone some major changes. Version 2.5 was the first commercial release in 1997. Version 5.2 builds significantly on the functionality of previous versions introducing a range of new analysis functions and sketch visualization.

The “Ecotect” tool offers a range of lighting analysis options. Its main focus is on natural lighting analysis. However, it can also analyse rudimentary artificial lighting design. “Ecotect” implements the Building Research Establishments (BRE) split flux method for determining the natural light levels at points within a model. This is based on the Daylight Factor concept. The Daylight Factor is a ratio of the illuminance at a particular point within an enclosure to the simultaneous unobstructed outdoor illuminance.

The basic analysis of natural illumination uses two types of corresponding definite skies as darkened and uniform to the models normalized for the Commission International of l'Eclairage (CIE). The geometric data of the place to analyse must be filled in. They are indicated by the coordinates of latitude and longitude as well as the orientation of the building. The results can be presented numerically (tables) and graphically as distinct formats: curves iso-lux.

5.2 “Desktop Radiance”

This program was developed by the department of technologies of buildings of the National Laboratory Lawrence Berkeley, California, United States.

Desktop radiance is a design tool that facilitates the design and analysis of buildings to optimize the efficiency of day lighting systems and lighting technologies. Desktop Radiance is a plug-in module that works with other popular computer aided design tools (CAD) to provide the user interaction and 3D modelling capabilities. Once created the 3D model, it can be detailed by using the Desktop Radiance library of materials, glazing, luminaries and furniture. As soon as the model is complete, the analysis parameters such as camera views or reference point calculations, building orientation and zone of interest has to be defined.

For the illumination analysis, the program uses a database with the geometric coordinates, timetable zones and some atmospheric data for some locations. The user is able to improve this database.

The "desktop radiance" tool allows presenting the data in tables and graphics through the analysis of images with the following options: levels of illumination directly on the image, iso-lux curves and FLD and levels of colours associated to the values of illuminance and luminances. Moreover, the program uses an interesting characteristic to filter the processed images and takes into account the sensitivity of the human eye.

6 RESULTS

In both programs, the properties of the materials used are described in Tables 2 and 3.

The obtained results for the overcast sky conditions, both by simulations and by "in situ" measurements, are shown in tables 4 to 10.

Table 4 shows the values of the exterior illuminances obtained "in situ" and with the two simulation programs.

Table 4 – Mean external horizontal illuminance

Room	External Horizontal Illuminance (E_{ext})		
	"In situ"	"Ecotect"	"Desktop Radiance"
B1 – Bedroom on the 1st floor	13 555	7703	13599
B3 – Bedroom on the 3rd floor	13 704	7703	13555
LR2w – Living room on the 1st floor	13 207	7703	13205
LR1w – Living room on the 1st floor	13 710	7703	12506
K0 – Kitchen on the ground floor	12 385	7703	12605
K1 – Kitchen on the 1st floor	13 716	7703	12385

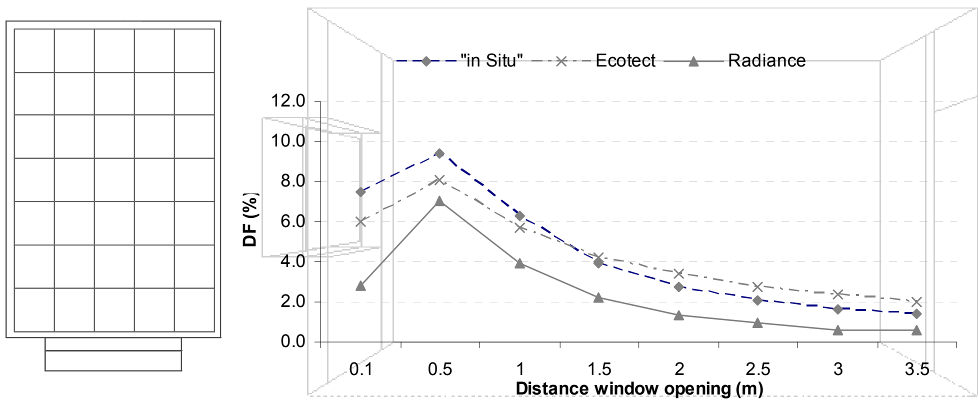


Figure 4 – Measurement grid and DF values for the bedroom on the 1^{st} floor

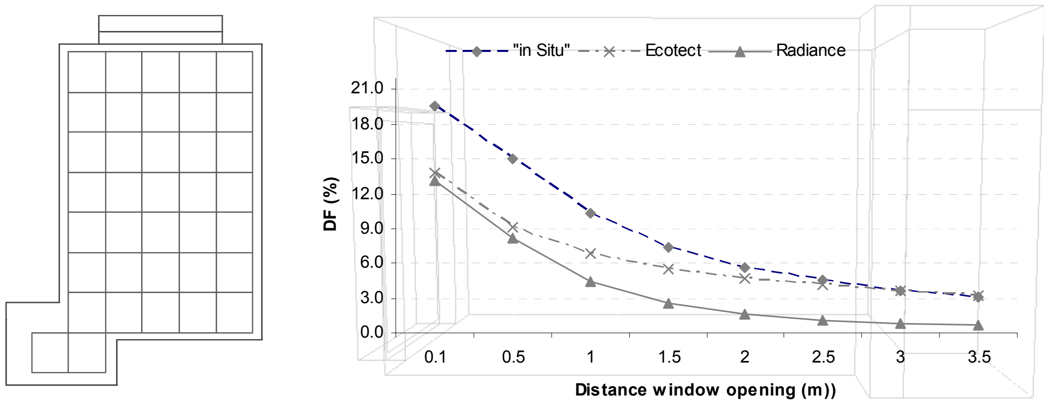


Figure 5 – Measurement grid and DF values for the bedroom on the 3rd floor

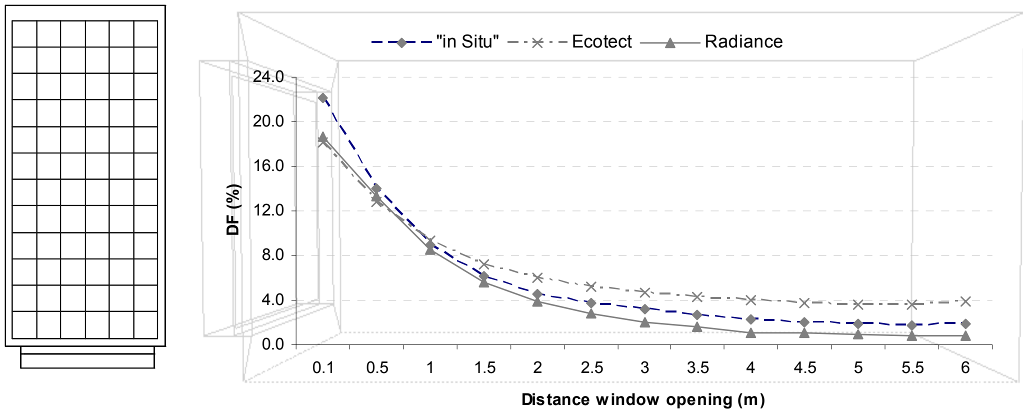


Figure 6 – Measurement grid and DF values for the Living room with one window

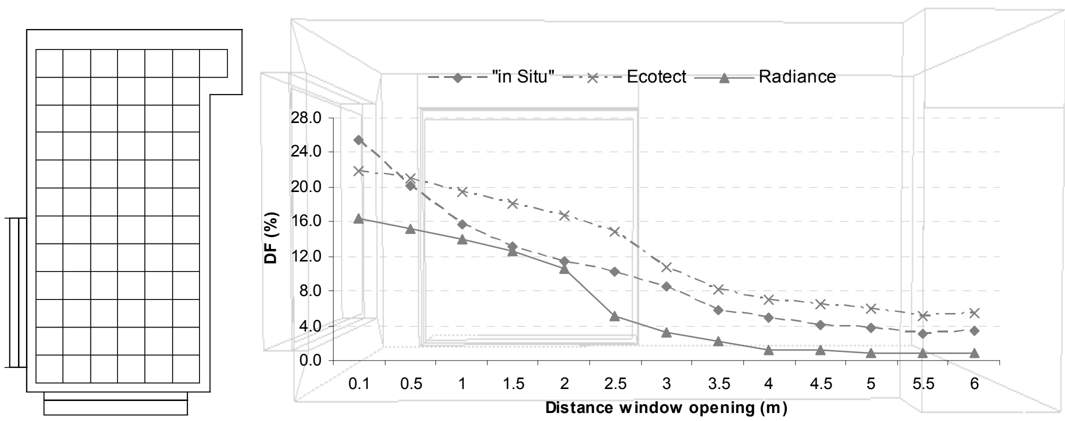


Figure 7 – Measurement grid and DF values for the bedroom on the 1st floor

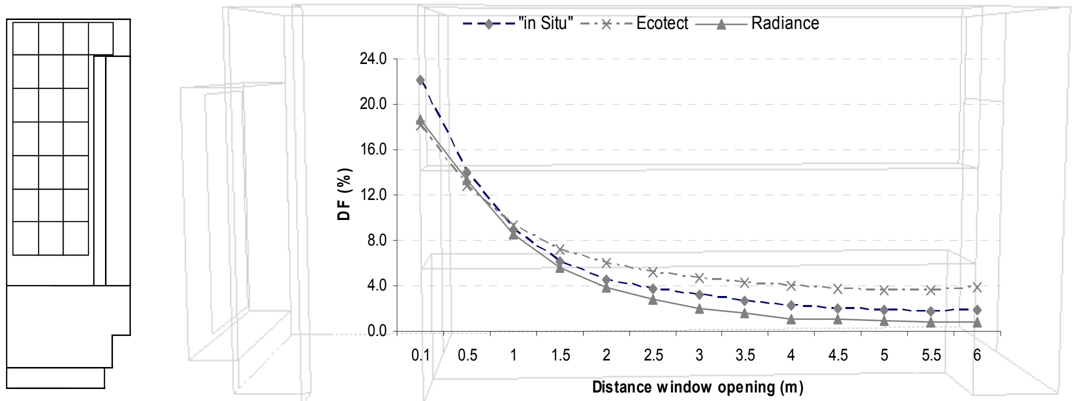


Figure 8 – Measurement grid and DF values for ground floor kitchen

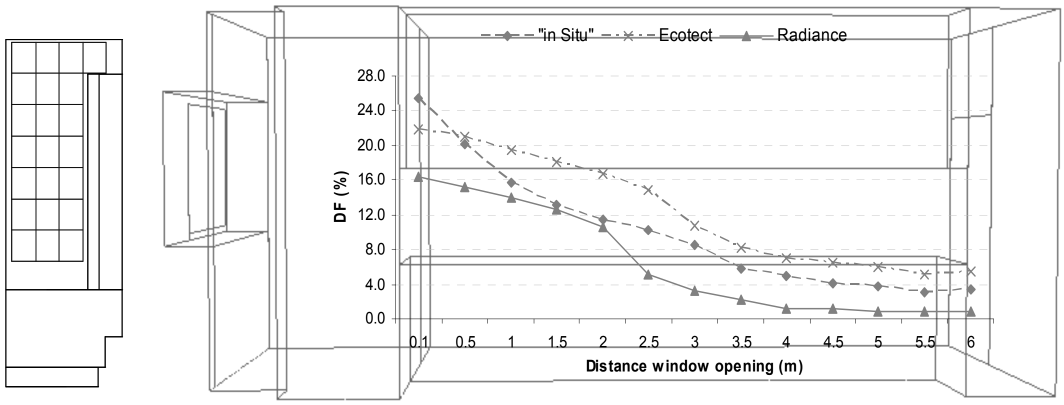


Figure 9 – Measurement grid and DF values for the kitchen on the 1st floor

Table 4 shows that the measured outside values of illuminance are similar to the ones obtained with "Desktop Radiance" but different from those obtained with "Ecotect". In any case, both simulated values follow the outside illuminance values:

E measured-outside / E measured-outside "Ecotect" = 1.7
E measured-outside / E measured-outside "Desktop Radiance" = 1

Table 5 presents the evaluation of the Daylight Factor in the studied rooms.

Table 5 – Evaluation of the Daylight Factor in the studied rooms

Room	DF (%) Recommended	DF (%) "in Situ"	DF (%) "Ecotect"	DF (%) "Desktop Radiance"
B1 – Bedroom on the 1st floor	≥ 0.5 % at 3/4 length	3.70	3.60	0.80
B3 – Bedroom on the 3rd floor	≥ 0.5 % at 3/4 length	1.70	2.30	0.50
LR2w – Living room on the 1st floor	≥ 1 % at 1/2 length	8.30	10.10	3.10
LR1w – Living room on the 1st floor	≥ 1 % at 1/2 length	3.10	4.60	1.90
K0 – Kitchen on the ground floor	≥ 2 % at 1/2 length	0.49	0.93	0.36
K1 – Kitchen on the 1st floor	≥ 2 % at 1/2 length	0.54	0.64	0.42

It is possible to observe that the daylight availability is good, satisfying the recommended values, in all living rooms and bedrooms. However, the kitchens do not meet the requirements. The main reasons for this fact are the dark colours of the pavements and furniture as well as the not favourable geometry of the windows and of these rooms.

It is also possible to see that, considering similar conditions, the "in situ" measurements show differences when compared with the values obtained by simulation for the illuminance values registered inside the rooms. It was observed the following ratio:

E measured-inside / E measured- inside "Ecotect" = 0.92
E measured- inside / E measured- inside "Desktop Radiance" = 1.68

The values listed in table 5 show that "Ecotect" usually lead to higher values of DF while "Desktop Radiance" lead to lower levels of this factor. In general, the real values are situated between the simulated values obtained with the two tools, as can be seen in figures 4 to 8. It is also possible to see that as the distance to the window increases, the deviation of the "Ecotect" values from the real values also increases.

7 CONCLUSIONS

Trough the "in situ" evaluation, as well as through the simulation tools, it is possible to conclude that only the kitchens do not accomplish the recommended values of DF.

In Portugal, statistic values for outside illuminances, by locality, do not exist, but they do not constitute a real difficulty on DF calculation with "Ecotect". The same is not true on the calculation of inside illuminance. This way, using "Ecotect" is necessary to introduce the adequate outside illuminance value for each region in order to not make evaluation mistakes of inside illuminance.

Although the outside illuminance values obtained with "Ecotect" are very different from the real ones, it should be kept in mind that this value depends on the place latitude and do not affect the inside DF value obtained in the room evaluation.

From the comparison of the real values with the simulated ones, it is possible to conclude that "Ecotect" tool lead to better results than "Radiance Desktop" tool. However, the use of these tools can be a priceless assistance on the choice of solutions that benefit the project in terms of luminic comfort, contributing in this way to the building sustainability.

8 BIBLIOGRAPHY

Batsford, Commission of the European Communities; Energy conscious design, a primer for Architect,Pub B.T. Batsford Ltd, 4 Fitzhardinge street, London W1HOAH, 1992.

Santos, A.J. – Desenvolvimento de uma metodologia de caracterização das condições de iluminação natural nos edifícios baseado na avaliação "in SITU"; Sector de edições e Artes Gráficas do LNEC, Lisboa, 2001.

SHE project - Sustainable Housing in Europe - European demonstration project funded within the 5th FP -Energy, Environment and Sustainable Development, Key Action 4 - Cities of the Future and Cultural Heritage (March 2003 œ February 2008).

Tabet, Kheira. & Shelley, Gary. "An investigation on the effect of access to windows on visual comfort, motivation and productivity. 3rd European Conference on Architecture, Florence, Italy. 17-21 May ,2003.

Manual do vidro – Saint Gobain, Ed. 2000.