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Current State and Challenges for Sustainable Development of Infrastructure

SYMPOSIUM 1
State Analysis and Condition Management of Buildings and Civil Infrastructure

SYMPOSIUM 2
Low-Energy Building Concepts
(new buildings and renovations)

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Symposium 1:	State Analysis and Condition Management of Buildings and Civil Infrastructure
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Organizers:

Finnish Association of Civil Engineers RIL

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Preface

Sustainable building and civil engineering means a new paradigm of developers with new requirements, objectives and solutions. Investors, the construction industry, professional services, industry suppliers and other relevant parties are facing the challenge towards achieving sustainable development, taking into consideration environmental, socio-economic and cultural issues.

This new paradigm embraces a design and management of buildings and civil infrastructures: targeting drastic improved energy efficiency, choice of materials, improved performance of the constructed assets as well as interaction with urban and economic development and management. the construction sector needs to develop skills and services to meet the customer and occupants requirements over the life-cycle of the assets. These cover knowledge in energy consumption, environmental impacts, indoor environment, safety, the adaptability of structures and premises, service life planning and facility management, as well as in life-cycle economics. on the customer side, this expertise will build on a closer cooperation between the bodies taking the investment decision and the services responsible for the operation and maintenance of the construction assets.

the objective of the EuroInfra 2009 Conference is to assemble people from practice, administration and research in order to report on and discuss a couple of defined key challenges for the sustainable development of infrastructure (buildings and civil infrastructures) in our societies. These areas are the themes of the two Symposia of this Conference: “State Analysis and Condition Management of Buildings and Civil Infrastructure” and “Low-Energy Building Concepts”.

the Conference Proceedings include 3 Keynote Lectures and additionally the written reports of the selected authors. the total number of the selected reports is 26: 12 of the Symposium 1, “State Analysis and Condition Management of Buildings and Civil Infrastructures” and 14 of the Symposium 2, “Low Energy Building Concepts (new buildings and renovations”.

the organisers of this EuroInfra 2009 Conference are the Finnish Association of Civil Engineers RIL and the European Council of Civil Engineers ECCE, with the co-operation and support of International Association for Life-Cycle Civil Engineering IALCCE, the International Council for Research and Innovations in Building and Construction CIB and the Finnish Innovation Fund, SITRA.

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Climate Change and Built Environment

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Abstract

The built environment consists of isolated buildings, villages, towns, networks (roads, sewers, energy …), that societies have constructed for their own needs (housing, manufacturing, transport, …). Climate has always been highly variable over time and space. One of the functions of the built environment is to protect persons and goods from climatic hazards. The very likely climate change resulting from huge green-house gases (GHG) emissions during the last century may lead to develop adaptation techniques in order to maintain an acceptable protection for humans. On the other hand, sound decisions were taken to try to limit GHG emissions. These mitigation measures start being implemented but their effect may not be effective before some decades. In the mean time, climate may change so that decisions we have to be taken now in a rather uncertain context. We propose to explore these two linked concepts: adaptation and mitigation in order to open discussion on options that could be taken.

Keywords: climate change, built environment, adaptation, mitigation

1. Introduction

The built environment consists of isolated buildings, villages, towns, networks (roads, sewers, energy …), that societies have constructed for their own needs (housing, manufacturing, transport, commerce, education …). All these items are obviously the result of human decisions and actions. The great variety of design, techniques and aspects anyhow results from the satisfaction of universal functions that will be further presented.

Climate, which has always been highly variable over time and space, is understood from the application of the laws of physics including planets movements' mechanisms, thermodynamics, fluid mechanics, chemistry … Observations and models allow short term predictions (weather forecast) as well as long term climate pattern projection. A major issue associated to the outcomes of these models is the uncertainty assessment.

The time scales of the built environment and of climate are radically different. The first cities were erected about 6000 years ago. Climate has been changing for hundreds of millions years.

The relatively stable climate, though variable, over the last six thousand years has very likely favoured the development of societies and correlatively of the built environment.

These anthropogenic developments have been huge and fast during the last hundred years. The associated production of green house gases (GHG) has been increasing as well as the concentration of these gases in the atmosphere. There is less and less doubt that this will contribute to impact climate during the next decades and centuries as concluded by the IPCC experts in their most recent report [1].

When considering both the extremely important increase of the built environment, also driven by an exponential demographic growth, and the perspective of climate change, societies are very likely to face serious questions concerning their ability to rapidly adapt to a new context.

To address these serious questions, this paper intends (i), to recall some basic elements about the past relations between the built environment and climate, (ii) to insist on two key concepts: mitigation and adaptation, (iii) to draw out some perspective for the construction community.

Within the scope of this paper, buildings (that may be considered as the “atoms” of urban areas) will mainly be considered. Civil engineering works are not forgotten at all but the focus on buildings reflects some realities. The shares of the building construction market and of the civil engineering market are respectively 70-80% and 30-20% in Europe ([2]). Buildings are at the same time a major GHG emitter and impacted by climate change due to these emissions.

2. Relations between the built environment and climate

Buildings are so common constructions that the question: “what is a building?” may look strange. This is in fact a very important question when addressing climate change issues.

Buildings have “ever” been built to satisfy a set of generic functions. Table 1 presents one such list of functions. The interest of this description is to show how these functions are closely linked. It also confirms the systemic character of a building. The art and skills of designers and builders are to find for each project an economical equilibrium that meets the objectives of the client (who should always plan and organise his construction maintenance).

The origin of buildings defects often comes from a loose respect of this fundamental balanced rule. Imprecise specification, loose design, incorrect implementation, inappropriate (or inexistent) maintenance are examples of such defects origins.

Table 1: functions of a building (adapted from [3])

	Function	Description	Comments
1	**Provide adapted spaces to carry out activities**	*This is the service provided by the building that allows users to have at their disposal suitable spaces as regard to activities which are to be carried out.*	Dimensions of spaces Access to spaces Spatial organisation
2	**Protect occupants and goods**	*This is the service provided by the building that protects users and goods against natural (climatic, seismic …), accidental (industrial gas emission, fire ...) or voluntary (aggression, theft ...) events.*	Capacity to withstand natural hazards or intrusion
3	**Allow access and use of goods and tools**	*This is the service provided by the building that allows occupants to use tools required by their activities and to take advantage of their goods.*	Energy, fluids and communication, Capacity to be equipped with adapted furniture
4	**Provide an adapted ambiance**	*This is the service provided by the building that allows the user to adapt indoor ambiance according to outdoor ambiance.*	Thermal, acoustic, olfactory, luminous, tactile ambiances. Well being
5	**Control relations between occupants indoor/outdoor**	*This is the service provided by the building that allows the occupants to control (choose, favour, avoid ...) their relations with others as well as with the environment.*	Control of sight, sound, smell, touch, light, electromagnetic fields ...
6	**Environmental "friendship"**	*This is the service provided by the building that allows occupants to live without impacting the environment.*	Control of liquid/solid/gaseous effluents Landscape impact
7	**Semiotics**	*This is the service provided by the building that reflects the quality of life of the occupants and creates the appropriation.*	Psychological/sensitive/architectural dimensions

The description of ancient buildings and of the first cities by historians shows that most of the technical and symbolic features of these early constructions were very similar to that of contemporary buildings.

This is for instance obvious for building functions such as the protection against wind, rain, heat, cold, …: walls, roofs, openings are universal solutions. Nevertheless, the detailed solutions imagined and developed by human groups are very diverse according to local climate, culture and resources. This fact becomes evidence when travelling in different countries (even in Europe).

Vernacular buildings were for long built using techniques developed pragmatically though trials and errors processes. The strong development of sciences since the XVIIIth century allowed a better understanding of building physics. This knowledge, together with the unprecedented industrial development that started in the XIXth century brought innovative ways to ensure building functions: new material such as steel, reinforced concrete, prestressed concrete, plaster boards, float glass …

The conjunction of all these innovations together with the availability of cheap energy resources dramatically changed the building industry during the XXth century. Demands for all-season indoor comfort requiring both heating and cooling equipments have for instance been constantly rising.

The most industrialised countries first used these technologies to develop comfortable buildings and there are no reasons why other countries would not demand for similar living conditions. A major issue in such a perspective is that these recently built, convenient and comfortable buildings consume an enormous amount of energy and it is now clear that the recent period of low cost energy may soon (at the human scale of time: within decades or maybe within one or two centuries) have an end as natural fossil fuels (oil, gas, coal …) reserves tend to decrease.

This fact, together with the exponential growth of the world population is one of the factors at the origin of the so-called “sustainable development”.

3. First decisions as regard to climate change

Once deciders were convinced of the potential link between climate change and GHG emissions, the first and sound decision taken in several countries to counterbalance this situation was to “turn off” the GHG taps. At the European level, the directive 2002/91/EC on the energy performance in building officialised this decision.

Reinforcement of thermal regulations was for instance decided. Use of renewable energy was promoted as well as the development of more efficient equipments. Most of these decisions are similar to that already taken after the 1973 first oil shock.

May new policies and their implementation avoid similar consequences than these previous policies in terms of reduction in rates and quantities of direct, natural ventilation to the habitable spaces of buildings, which impacted indoor air quality.

For several reasons (economic issues, importance of the stock, questions about the readiness of the buildings production tool, time needed to raise awareness of stakeholders …) it will take decades to observe the effects of these efforts in terms of a decrease of GHG concentration. From a geopolitical point of view, the decisions that will take heavily populated countries such as China or India will also impact the future situation.

In the mean time, mainly due to the inertia of atmospheric processes, climate may change locally and the question of adaptation to a new climate scheme has to be addressed.

The adaptation issues raise challenging questions:

- do present design rules, construction products and site implementation organisation fit with this new climatic context for new buildings?

- what is the vulnerability of existing buildings?

- if relevant, how can vulnerability of existing buildings be increased under acceptable economical conditions?

- what is the influence on vulnerability of actions aiming to reduce GHG emissions for both new and existing buildings?

Of course the pertinence of these questions relies on local climatic projections for the next decades and a close cooperation with climatologists is absolutely necessary. This cooperation is effective in many research programmes as well as in the IPCC group.

4. Mitigation and adaptation

Mitigation concerns all the measures that have mostly already been taken and are being implemented to limit GHG emissions. In addition to the reinforcement of thermal insulation, the pallet of mitigation measures encompasses bioclimatic design closely linked to local climate, efficient equipments with adapted controls, occupants' behaviour including careful building maintenance.

Adaptation concerns all the measures that can be taken to limit the impacts of a new climatic context. It aims to anticipate local climate change impacts on the built environment.

Whilst the mitigation concept is easily understood as it refers to short term actions and measurable expected benefits (a measurable energy consumption decrease can be normally observed during years following the reinforcement of a building thermal insulation), the concept of adaptation is more difficult to explain.

Adaptation refers to both immediate decisions (I am cold, I put on a pull-over) and long term effects (long term meaning for the next generations) for which costs of decisions have to be paid now.

The first example concerning my immediate decision to put on a pull-over is very close to mitigation measures (I insulate my building): I expect an immediate (or short term) benefit. The second example refers to decisions in a rather uncertain context.

In this latter case, sound questions have to be raised as the expected benefits are both on the long term and uncertain: Can't I use my resources for something else with more immediate benefits? How can I assess the consequences of not taking adaptation measures?

These questions are similar to insurance questions: what is the probability an event occurs? What could be the consequences for me and my relatives in case the event happens? How could if impact my business? How much am I ready to pay for consequences in case it happens? Insurance companies have their own answer: insurance is cheap before the event!

Figure 1 illustrates the links between mitigation (of GHG emissions) and adaptation (to the effects resulting from climate change) of the built environment.

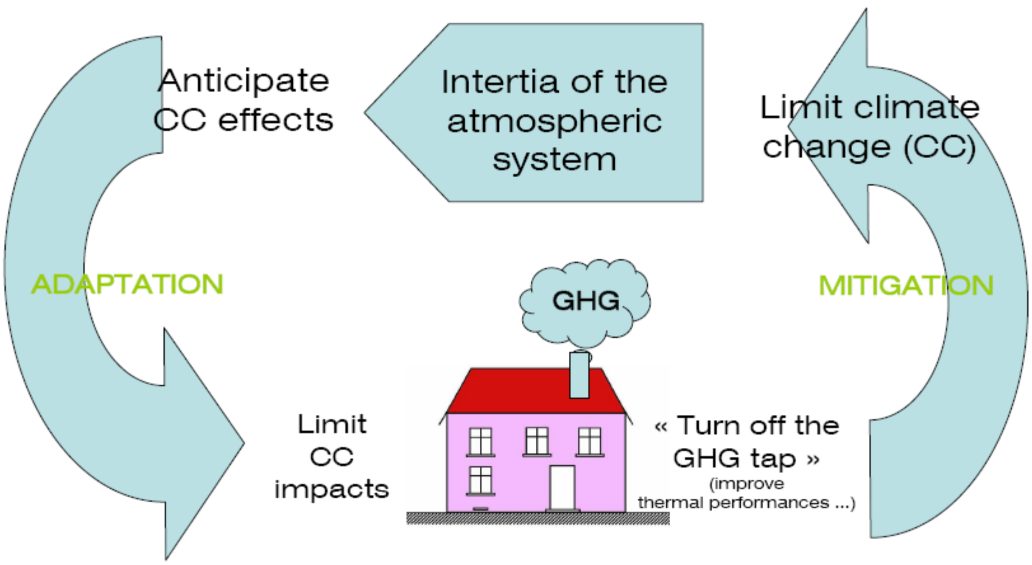

Figure 1: link of construction with climate change: mitigation – adaptation

As mitigation and adaptation are linked together, care must be taken to adopt coherent measures in order not to limit their respective expected impacts. The two following examples illustrate this:

1. During a very hot period in Paris during summer 2006, a hairdresser installed a split air-conditioner system in order to create a comfortable enough indoor climate for both his clients and himself. The door on the street was left open and the light on. This investment for this spontaneous adaptation is a few hundreds of euros. The generalization of such behaviours may lead, as observed in 2003 in France [4], to peak electricity demands (generally produced by fossil fuel plants). The question raised by this example is: what else can be done to allow the hairdresser to work normally whilst limiting GHG emissions?

2. The satisfaction of high noise attenuation is easily reached with “thick” concrete slabs. The resulting strong link between floors and walls creates an intrinsically safe structure. The drawback of this situation is an important thermal bridge at the junction. In order to reduce this thermal bridge, thermal barriers are being introduced that may weaken the structure under strong wind effects, decreasing the adaptation capacity in case of such climatic event (the risk is increased with use of modern wind-resistant windows).

Taking care of these issues will demand more cooperation between designers, manufacturers of construction products and contractors. This is then a chance for a better building quality.

5. Adaptation: a challenging urgency

Referring to the IPCC reports and other publications, global climate change is very likely to happen in the next decades. This means that the whole built environment, both existing buildings as well as new buildings to be built from now, could be impacted. The difficulty is then to take decisions now with a relative confidence in local climate evolutions for the near future (20-30 years ahead).

This kind of projection is very challenging for climatologists. The near future time-horizon is rather “empty” between seasonal forecasts, which can be adjusted from observations, and long term projections that reflect main evolution trends. Nevertheless, both models and observations converge towards a very likely global temperature increase of 1°C +/- 0,5 °C in 2030 and this perspective is rather independent of emission scenarios due to the inertia of the atmospheric system.

Even in case of a complete stop of emission today, this perspective would not be affected [5]. The natural variability of climate will of course participate in this global evolution. It is in particular driven by identified ocean natural phenomenon (AMO : Atlantic Multidecadal Oscillation, and PDO : Pacific Decadal Oscillation) which are still not very well taken into account in climate models. Progresses in understanding these phenomenon and their impact on global climate change are awaited from observations and improved models.

Downscaling methods allow small scale (kilometre, hectometre) climatic projections from global model results. Though the climatic variability is higher at a regional scale (Europe is for instance a region for climatologists) than at a global scale, general trends over long periods are quite similar. Local projections take into account the local geography but results highly depend on the quality of data at a more global scale. One of the research priorities is to assess uncertainties in order to be able to define pertinent adaptation measures.

Defining adaptation measures is then a challenging urgency as it consists in decisions to be taken during the following years in order to cope with a near future climatic situation which is difficult to precisely describe but that may only slightly depend on mitigation measures effectiveness.

At the same time, mitigation measures are promoted that should not only be considered under energy criterion (reinforcement of thermal insulation, introduction of efficient equipments). A building is much more than a thermal energy system. Moreover, buildings life cycle time are generally built for decades (even more for civil engineering works).

6. Climate Change Issues: what may change?

As already mentioned, the built environment and climate have always had “intimate relationships”. The perspective of a climate change should then not be a domain where construction stakeholders are inexperienced. They have proved for long their ability to develop suitable solutions for a wide range of climate, using local resources to mass-produce buildings for a great variety of purposes. In fact the main difference with past is that the very likely climate change may come within a very short time compared to the period that was needed to develop these clever and locally adapted solutions we now know and use.

The challenge is to be able to react very quickly (within a generation?) whilst centuries were needed to develop the present current methods, technologies and production organisations even if most of these know-how were industrially developed during the last century.

What may then change?

Change is probably needed in different domains such as procurement, design, production organisation, construction technologies, skills, behaviour of occupants …

This is a real challenge as the innovations that may emerge from or support these changes probably have to be successfully introduced within a very short period of time (quite instantaneously at the societies scale of time). Table 2 presents a synthesis of improvements for a set of current natural hazards that may be locally modified in case of climate change.

Table 2: examples of adaptation measure to cope with climate change impacts

Natural hazard / main climatic parameters	Available methods	Improvement in the perspective of climate change
floods / rain falls	- knowledge on local phenomenon as well as on impacts (on river water levels) - mapping of flood-prone areas - set of prescriptions of new and existing buildings	- necessity to develop an appropriate territory approach (water basin) - technical innovations (protection systems, amphibious buildings) - evolution of insurance schemes
Shrinking-swelling of clay soils / temperature and rainfalls	- foundations dimensioning rules - mapping of clay subsidence areas	- appropriate use of existing rules - controls - evolution of insurance schemes - develop tools to assess vulnerability of
Wind / pressure, temperature	- structures dimensioning rules	- examine the pertinence of the revision of rules - resilient buildings
Heat-wave / temperature	- oral transmission of behaviour - heat-wave plans	- develop tools to assess vulnerability of urban areas - technical innovations (summer comfort without GHG emissions)

The example of clay soil subsidence illustrates the context under which such improvements should be carried out. The phenomenon of clay soil drying subsidence and rehydration swelling has been observed for long. It is rather well described and the cost of repair is known to be very high in all concerned countries. It mainly concerns shallow founded buildings. Cracks and structure failures are the most common consequences. To avoid them, technical solutions are known but the diffusion of these good practices has to be supported by a constant effort of information and training.

In all these countries, a set of measures were adopted ranging from recommendations to regulations and controls (concerning design, soil characteristics determination and skills of stakeholders).

Due to a shared knowledge on the laws of physics, all these measures point out common technical issues such as:

- the determination of foundation depth according to the local clay soil characteristics,

- the design and realisation of foundations as a function of the potential soil subsidence,

- the care to be taken about the choice of trees to be planted at a minimum distance of building foundations,

More interestingly, countries differ in the implementation of these rules. Depending, among other parameters, on the construction defect insurance scheme, the organisation of stakeholders shows a great diversity. The kind of control (before or after the construction, systematic or not, just in case of defect …) indicates the existence of diverse approach of natural risk.

These diverse organisations reflect cultural issues and, even if one system was definitely better than all other ones, the transfer to other countries would probably meet some difficulties because it would introduce important changes in the current (tradition-based) construction process.

This example illustrates that we probably do not miss technical solutions to cope with natural hazards but that we have to drastically improve their implementation.

7. Climate change issues and building sustainability

A sustainable building is first of all a building. As such, it is a system that aims at fulfilling functions directly related to the programme of the construction operation, which describes the intentions and expectations of the client with respect to his budget.

The precise definition of these functions (as presented for instance in table 1) and their relative weight depends on each particular operation. The functions of an office building are different from that of a housing building.

Sustainability is not an additional function but is incorporated in these generic functions through a thorough reflection starting at the early beginning of a construction operation. This reflection aims at incorporating environmental, economic and social issues over the built environment life-time.

Whilst ensuring basic performances, sustainability brings new dimensions linked to a holistic approach of the construction in relation with its environment.

The aspects of sustainable built environment are then plural and extend traditional considerations, focussed on the construction phase, to time, space, economic, energy and environment issues.

Sustainability could be seen as a movement towards a rural construction economy characterised by an efficient use of local resources to build locally adapted buildings. The challenge for the XXIst century is to succeed in this direction with an exponential demography, a fast growing urban population looking for more comfort, a perspective of relative scarcity for some natural resources and a very likely modified but locally uncertain climate.

Sustainability will not be achieved by only implementing fashionable equipments/building parts such as photocells roofing or over-insulated walls. It needs a much deeper transformation of the construction process starting from a comprehensive expression of the future use of the building including users' behaviour and maintenance conditions.

According to the particular context of each construction operation, the best way to satisfy the building functions may be to use photocells roofing or over-insulated walls but this decision is an output of the construction design process, not an input.

Introducing climate change issues in a sustainable built environment project should not be a major challenge for a properly managed sustainable project. In such a project, raising questions concerning the integration of mitigation and adaptation measures should mobilize the holistic approach of sustainability.

Mitigation will be naturally integrated because of the predominant importance of energy issues in sustainable buildings projects. Adaptation to a changed climate requires more anticipation and as precise as possible appreciation of the characteristics of a modified climate. Assumptions, based on likely climate evolutions should be taken into account in order to assess the vulnerability of design options to climatic hazards.

8. Conclusions

From this very brief overview of some issues triggered when thinking both of climate change and (sustainable) built environment, we would like to raise some concluding remarks as well as some questions.

Remarks:

- construction actors have proved for long their ability to design, build and maintain buildings adapted to local climatic conditions,

- sustainability issues and climate change issues rather show synergy as they both require a holistic approach of the built environment,

- climate change issues adaptation issues may help not to restrict sustainability to the unique energy dimension, as it is has been very often the case up to now,

- taking into account climate change issues may significantly improve building quality as both mitigation and adaptation require a more thorough attention at each step of the building project.

Questions:

- raising awareness on mitigation issues already mobilizes a lot of resources (promotion of innovation, training …): how can adaptation issues be introduced without bringing confusion? (Adaptation is sometimes perceived as a sign of ineffectiveness of mitigation measures).

- can insurers play a specific role to support win-win actions: better quality resulting from mitigation/adaptation versus adapted insurance contracts?

- under which conditions are both construction professionals and clients able to integrate rapidly (some decades) potential drastic changes?

- how do we assess the vulnerability of existing constructions and decide of reinforcement measures when needed?

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Efficient lifetime management of civil infrastructure: Recent accomplishments and future directions

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Abstract

In a context of scarce financial resources, stakeholders need decision making tools to determine best management strategies of their facilities. The combination of structural performance analysis with economic analysis allows stakeholders to broaden their perspective and include maintenance, repair, rehabilitation and replacement costs. Nowadays, one great challenge is to use structural health monitoring methods and concepts in the general assessment and maintenance frameworks of civil infrastructure when determining optimal maintenance strategies. The primary objective of this paper is to highlight recent accomplishments in the life-cycle analysis of civil infrastructure including performance assessment, maintenance, monitoring, management and optimization of deteriorating structural systems under uncertainty. A lifetime probabilistic approach is proposed to include uncertainties inherent to the problem of structural deterioration of civil infrastructure. This approach is illustrated on an existing bridge.

Keywords: Lifetime Management, Structural Health Monitoring, Maintenance, Cost, Optimization, Civil Infrastructure.

1. Introduction

Efficient assessment and maintenance of buildings and civil infrastructure have become of paramount importance in most countries. Structures and infrastructures play an increasing role in the productivity and organization of societies. However, in the meantime, they are experiencing severe deterioration due to natural hazards, aging, and increased structural performance demands [1]. To tackle the problem of structural deterioration, efficient civil infrastructure management systems should provide an accurate framework for optimization of maintenance strategies under uncertainty and limited financial funds (Fig. 1). As structural health monitoring (SHM) enables to keep strength deterioration processes under control [2], its integration in the life-cycle performance analysis is considered as a significant and rational tool [3-8].

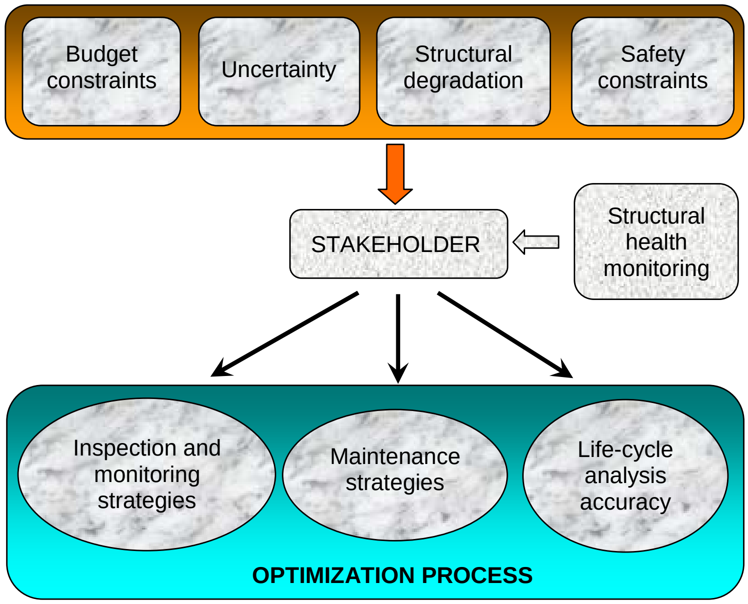

Fig.1 General framework for optimization of civil infrastructure maintenance strategies under constraints and uncertainty.

The objective of this paper is to shed light on recent accomplishments associated with the analysis of life-cycle cost analysis, integration of SHM, and optimization of maintenance strategies. The organization of the paper is as follows. First, recent accomplishments in the integration of SHM in the structural performance analysis are presented [9]. The structural performance indicator used in this paper is associated with reliability of structural systems. Such indicator is a practical measure that enables to include uncertainties inherent to resistance and loading phenomena in the life of civil infrastructure. This measure has been intensively investigated in previous studies [10-29]. The probability of failure of a system is defined as the probability of violating any of the limit state functions that define its failure modes. The case of a limit state function relating the resistances of the structural components to the load effects acting on these components is considered as example. Safety margins at a point in time *t* are expressed as follows

$$M(t) = R(t) - Q(t) \tag{1}$$

where $M(t)$ = instantaneous safety margin, $R(t)$ = instantaneous resistance, and $Q(t)$ = instantaneous load effect.

Second, a framework that optimizes maintenance strategies, based on monitoring data, is proposed [30]. The approach emphasizes the determination of maintenance strategies (Fig. 1) in the optimization process. The objective is to provide stakeholders with optimal maintenance strategies so that they can allocate financial funds for maintenance actions in the best way. Finally conclusions are drawn and future directions are identified. The I-39 Northbound bridge, over the Wisconsin river (Fig. 2a), long-term monitored by the National Center for Advanced Technology for Large Structural Systems (ATLSS), at Lehigh University, Bethlehem, Pennsylvania, offers the opportunity to perform studies including monitoring results in assessment and maintenance frameworks. Controlled load tests and long-term monitoring programs were performed on this bridge in 2004. The instrumentation consisted of installation of weldable resistance strain gages at key locations to understand the response of the bridge under traffic (see Fig. 2b for location of sensors of interest in this paper) [31].

(a)

(b)

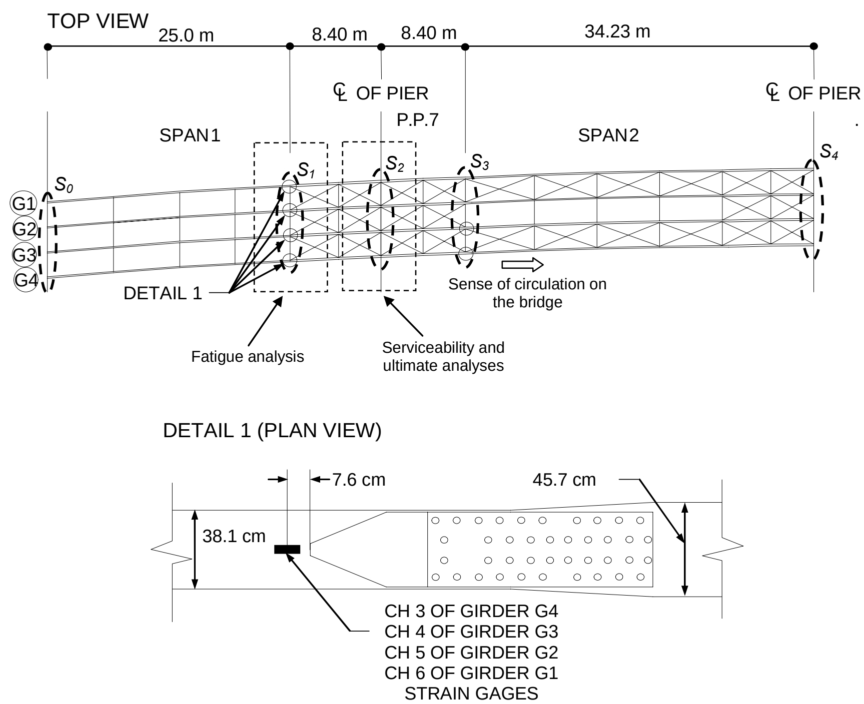

Fig.2 Top view of spans 1 and 2 of the Wisconsin Bridge and (b) plan view of sensors at detail 1 in Fig. 2a (adapted from [31]).

2. Integration of SHM in lifetime management of civil infrastructure

Prediction models of the performance of structures and infrastructures over time are by nature complex and uncertain. Since they are sensitive to changes in input parameters, use of SHM is a powerful mechanism to reduce uncertainties and calibrate some parameters of the model. Reductions in size, wireless capacities, improved energy performance, and reductions in cost are making SHM practical for civil infrastructure applications [1]. There is now an urgent need for methodologies that integrate monitoring information in the lifetime management of infrastructures. Some concepts to make this integration practical are analyzed herein through examples concerning the Wisconsin bridge [9]. First, controlled load tests results are used to determine in situ live-load distribution factors for each girder of the Wisconsin bridge (Fig. 2a) when trucks move through the bridge on different lanes. Second, daily histograms for stress ranges are obtained from sensors measurements during long-term monitoring program. These histograms enable to calculate a daily effective stress range and to perform a fatigue reliability analysis. Third, long-term monitoring results are used to approach the extreme moment due to heavy trucks and determine the probability that this extreme moment is larger than the moment capacity of each girder. The impact of monitoring information on the structural information is each time analyzed and discussed.

2.1 Use of controlled load tests

Calibration of some parameters is illustrated herein with the example of the assessment of live-load distribution factors (for the girders bending moment) by using controlled load tests results. Such parameters are usually provided by codes specifications. They depend on the number of lanes loaded and are different for exterior and interior girders. Controlled load tests enable to assess directly live-load distribution factors for the Wisconsin bridge. The monitoring of the structural response to the moving truck load is performed through strain measurements at sensors locations. In all tests, trucks travel northbound and the controlled load tests start at the south abutment (section S_0 in Fig. 2a) [31]. One girder of the multi-span I-39 bridge is also modeled, using finite elements and the influence line IL_0 is calculated for this girder in section S_1. Distribution factors are assessed by comparing the controlled load test influence line for each girder in S_1 [9] with the calculated influence line IL_0 and by applying a weighting coefficient to IL_0, with constraint that the peaks of the two influence lines match in section S_1 (the weighting coefficient is then multiplied by a multiple presence factor of 1.2 to determine the distribution factor). The influence line for moment obtained by the controlled load test for sensor CH3 is shown in Fig. 3a when the truck is on the right lane, and IL_0 (for an exterior girder) is shown in Fig. 3b.

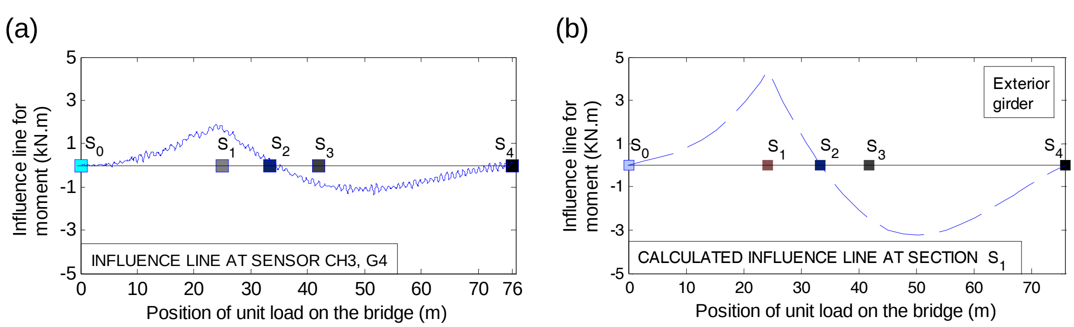

Fig. 3 Influence line in section S_1 (position of unit load is 0 when the load is at section S_0) obtained with controlled load test (heavy truck on the right lane) associated with CH3 of girder G4, and (b) IL_0 (calculated for an exterior girder) in section S_1.

The reliability associated with serviceability (with respect to permanent deformation under overload) is assessed from the beginning of the life of the structure until the end of the service life by calibrating distribution factors of AASHTO specifications with in situ controlled load tests results after year of monitoring program [9]. Reliability index profiles are provided for girders G2 and G4 in Fig. 4. Distribution factors are updated for these two girders at year 43 using controlled load tests results as explained previously. For some components like girder G2, the distribution factor calculated from controlled load tests is higher than the one provided by AASHTO codes and there is a decrease of the reliability index at year 43 (Fig. 4). Conversely, for girder G4, SHM data used at year 43 decrease the value of the distribution factor and there is, therefore, an increase in the reliability index at year 43 (Fig. 4).

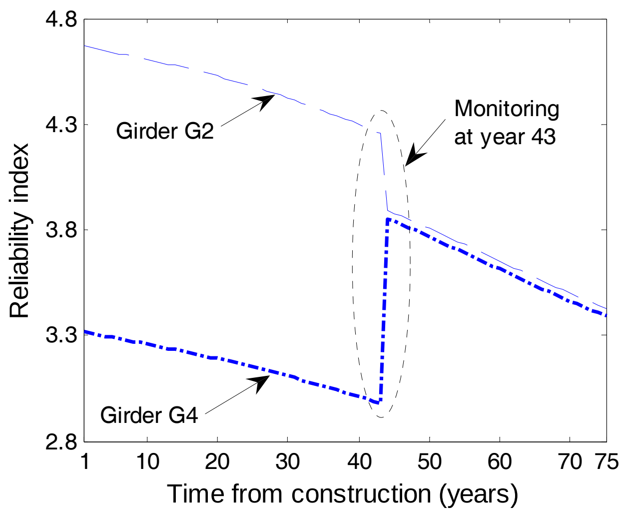

Fig. 4 Reliability index profile for serviceability that uses AASHTO specifications by including new distribution factors at year 43 for girders G2 and G4.

The use of controlled load tests data shows that some parameters can be directly assessed by in situ tests, which can finally improve the accuracy of both the structural and the reliability analyses.

2.2 Use of long-term monitoring

The monitored strain data from the uncontrolled load tests (under each of the passages of the heavy vehicle traffics) were extensively collected and investigated during the period from August 12 to November 3, 2004. These data are used herein in two different ways, first to lead a fatigue reliability analysis in section S_1 and second to perform a serviceability reliability analysis in section S_2 (Fig. 2a). Daily histograms for stress ranges are obtained from sensors measurements in section S_1. These histograms enable to calculate a daily effective stress range (shown in Fig. 5 for channel CH5 of girder G2). This information is used to determine the daily number of cycles N_d, and the number of cycles to failure N_c [30]. This enables to perform a fatigue reliability associated with the number of cycles to failure. The associated reliability index for fatigue of details in section S_1 of girder G2 is shown in Fig. 6.

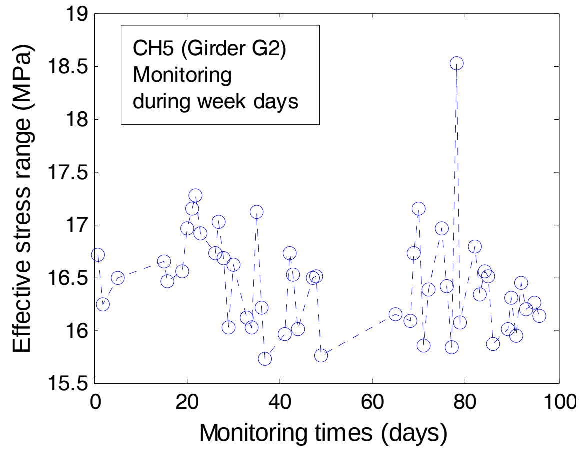

Fig. 5 Daily effective stress range for detail located at channel CH5 based on the measurements during week days.

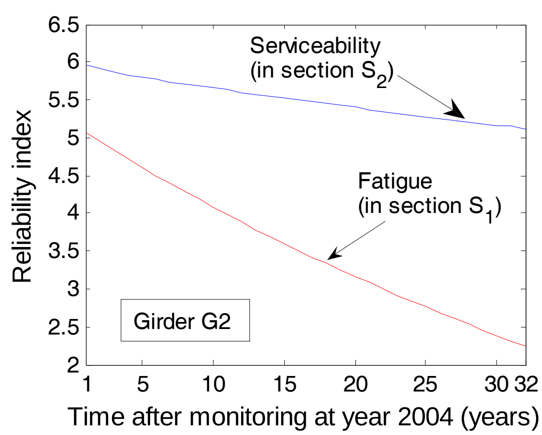

Fig. 6 Reliability index profiles for fatigue in section S_1 and for serviceability in section S_2, for girder G2.

Long-term monitoring data are also used to perform a serviceability reliability analysis in section S_2 (Fig. 2a) by using statistics of extremes (extreme values are understood as largest values of a random variable herein). It is reminded that in a set of observations (e.g. SHM data), extreme values can be modeled as random variables. Long-term SHM allows to approach the extreme moment histograms due to heavy trucks in each girder in section S_1 (Fig. 2a). The histograms of the extreme moment are then assessed in section S_2 by multiplying the moment in section S_1 by the ratio between the maximum absolute values of influence lines (by modeling the bridge with finite elements) in sections S_2 and S_1. The Gumbel PDF [32] for girder G2 is shown in Fig. 7.

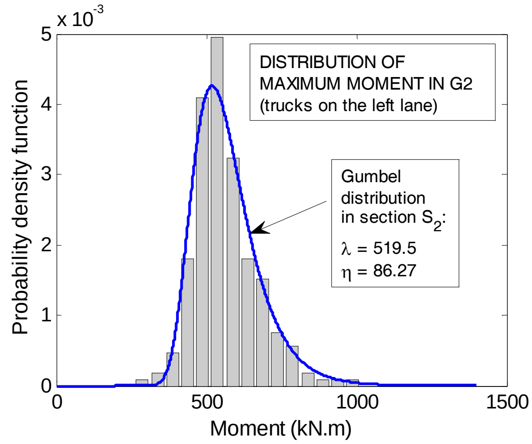

Fig. 7 Assessed histogram and best fit distribution in section S_2 for girder G2

PDFs (probability density functions) of extreme values recorded during monitoring program are used to predict the future extreme values of moment due to traffic in each girder. The reliability index profile associated with this limit state is provided in Fig. 6. Finally, as for controlled load tests, long-term monitoring enables to complete and update the structural reliability analysis in an efficient way. It is evident with these examples that lifetime management methods stand to benefit from integrating monitoring information, as SHM techniques effectively capture structural behavior and demands of a structure. Whereas SHM has focused primarily on damage detection, there is now a strong motivator in including this information in lifetime management of civil infrastructure to improve the accuracy of the lifetime analysis and determine future maintenance strategies in the best effective way.

3. Optimization of maintenance strategies

Optimization is the essential tool for providing best decision support in the field of lifetime management of civil infrastructure. The advances in computation and optimization methodologies allow to develop complex optimization frameworks. How to integrate monitoring data into a maintenance strategies optimization framework is still a challenge and recent accomplishments are analyzed herein. The main objective of civil infrastructure management systems is generally to spend the minimum possible amount of financial resources, keeping the structures as safe and serviceable as possible [30]. To deal with these two conflicting criteria, a bi-objective optimization process is proposed and the maintenance strategies are schematically illustrated in Fig. 8. Expressed in a general way, the design variables in this problem are the set of maintenance application times $T = \{\tau_1, \ldots, \tau_n\}$ until the end of the service life T_f and maintenance types $\Omega = \{\omega_1, \ldots, \omega_n\}$ (see Fig. 8).

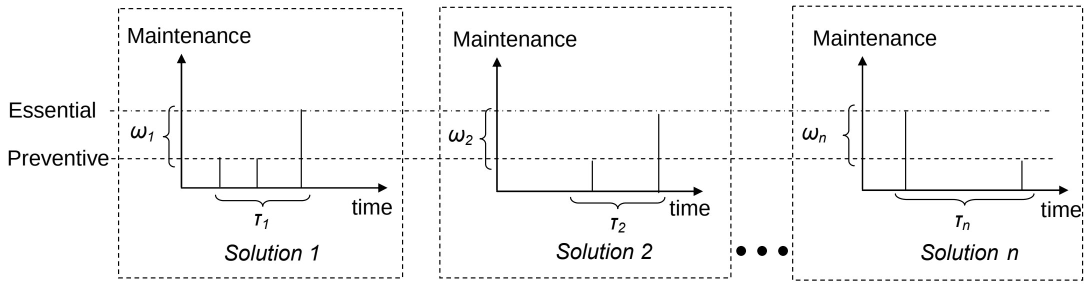

Fig. 8 Schematic representation of optimal maintenance strategies set (including preventive and essential maintenance actions).

Optimal solutions are searched by minimizing both the cumulative maintenance cost and the cumulative expected cost of failure at T_f, such that constraints on reliabilities are satisfied. The reliabilities considered in [30] are associated with fatigue, serviceability, and ultimate structural capacity, based on monitoring data as shown in section 2. NSGA-II (Non-Dominated Sorting Genetic Algorithm) program reported in [33] is used to find optimal solutions (also called Pareto solutions) set of this bi-objective optimization problem. The examples of fatigue limit state in section S_1 (with constraint β_{f0} = 1.5) and ultimate structural capacity limit state in section S_2 (with constraint β_{u0} = 2.0) are analyzed herein. The group of trade-off solutions for the bi-objective optimization concerning fatigue actions is indicated in Fig. 9a when (a) considering only fatigue limit state (Pareto front F_1), or (b) when considering fatigue and ultimate structural capacity simultaneously (Pareto front F_2).

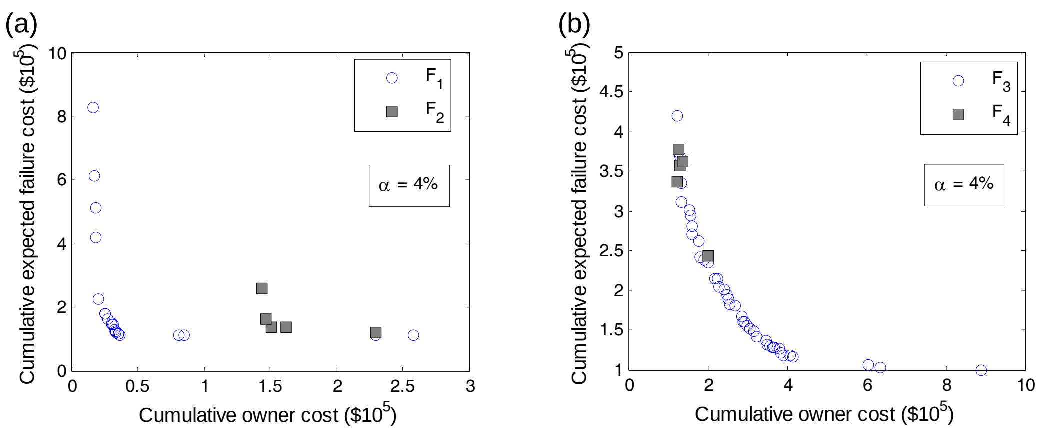

Fig. 9 Comparison of Pareto fronts (a) F_1 and F_2, and (b) F_3 and F_4; α = yearly discount rate of money.

It is shown that costs of solutions in set F_1 do not match those of solutions in set F_2. In addition, the group of trade-off solutions for the bi-objective optimization concerning ultimate structural capacity is indicated in Fig. 9b when (a) considering only ultimate structural limit state (Pareto front F_3), or (b) when considering fatigue and ultimate structural capacity limit states simultaneously (Pareto front F_4). It is shown that costs of solutions in set F_3 are very close to those of solutions in set F_4. From these results, it is obvious that taking decisions when considering several limit states simultaneously can lead to optimal solutions dramatically different from those that would be obtained if limit states are considered separately.

4. Conclusions

This paper presents a general reliability-based framework for optimization of maintenance strategies of civil infrastructure, based on SHM information. The use of SHM in a general reliability framework is a timely challenge and the proposed approach provides concepts and ideas to make this use possible in a practical way. The proposed approach is illustrated with the case of a steel bridge that was monitored in 2004. The following conclusions can be drawn.

1. SHM programs can be used to calibrate, update, and finally improve structural reliability models by reducing uncertainties. An optimization procedure that integrates SHM information and deals with various limit states is used to determine optimal maintenance strategies. It has been shown that optimal solutions cannot be seen as a juxtaposition of optimal results for different limit states taken individually and that lifetime management has to be considered as a whole at the scale of the civil infrastructure and not for each failure mode considered individually.

2. Improvements of probabilistic and physical models for evaluating structural deterioration is still a challenge and the lack of data available on the effects of realistic interventions is a major issue for lifetime management of civil infrastructure systems. Error associated with model of the structural performance is of paramount importance and should be considered in future studies.

3. Assessment of the current state of civil infrastructure can serve as basic information for the formulation of technical and political strategies on the optimal management of infrastructure for a sustainable future. Future studies should enhance the integration of uncertainties inherent to the assessment process (inspection and monitoring strategies) and optimize assessment strategies. The objective of recent and future research studies is to pave the road for flourishing future civil infrastructure management systems towards creating platforms and formulations for efficient reliability-based assessment and optimum maintenance strategies under uncertainty.

Acknowledgments

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From the energy evaluation to the assessment of the whole building performance

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Abstract

Buildings are significant factors of all national economies. In order to label their quality and building performance, standardized evaluation methods are necessary. These methods should contain a high level of detail on one hand, and be as clear as possible and easy to understand for the user on the other hand, priorities differ according to the building type (housing, office, etc.). The following report will show the actual situation and the further development in Germany: the way from the energy evaluation (Energy performance certificate) to the future assessment of the whole building performance – the German Certificate for Sustainable Buildings (DGNB).

Keywords: German Certificate for Sustainable Buildings (DGNB), certification, assessment of building performance, energy performance certificate

1. Function of buildings

Buildings have numerous functions. Essentially, these are technical as well as social and cultural functions that are performed under the consumption of resources. The minimization of this resource consumption under consideration of the function and the location is named sustainable building.

The most important technical functions are:

Protection against:

- People and animals (safety need)
- Fire in the neighbourhood and on one's own premises
- Moisture in the form of precipitation, formation of surface condensation and mould, frost effects, swelling and shrinking processes
- Cold, when the outdoor temperature is low
- Heat, under mid-summer conditions and/or high internal heat loads
- Noise from the outside and from neighbouring other, or own, home or working areas
- Electric fields and radioactivity
- Glare problems due to direct or reflected solar radiation

Provision of:

- Light, preferably using a maximum share of daylight and high energy-efficiency artificial lighting
- Heat, to ensure thermal comfort when outdoor temperatures are low
- Cooling, to prevent overheating
- Humidity, in particular for use(r)-related requirements
- Fresh air, as available or conditioned
- Room acoustics, to ensure sufficient speech intelligibility and/or the requested auditory sensation of music

Removal of:

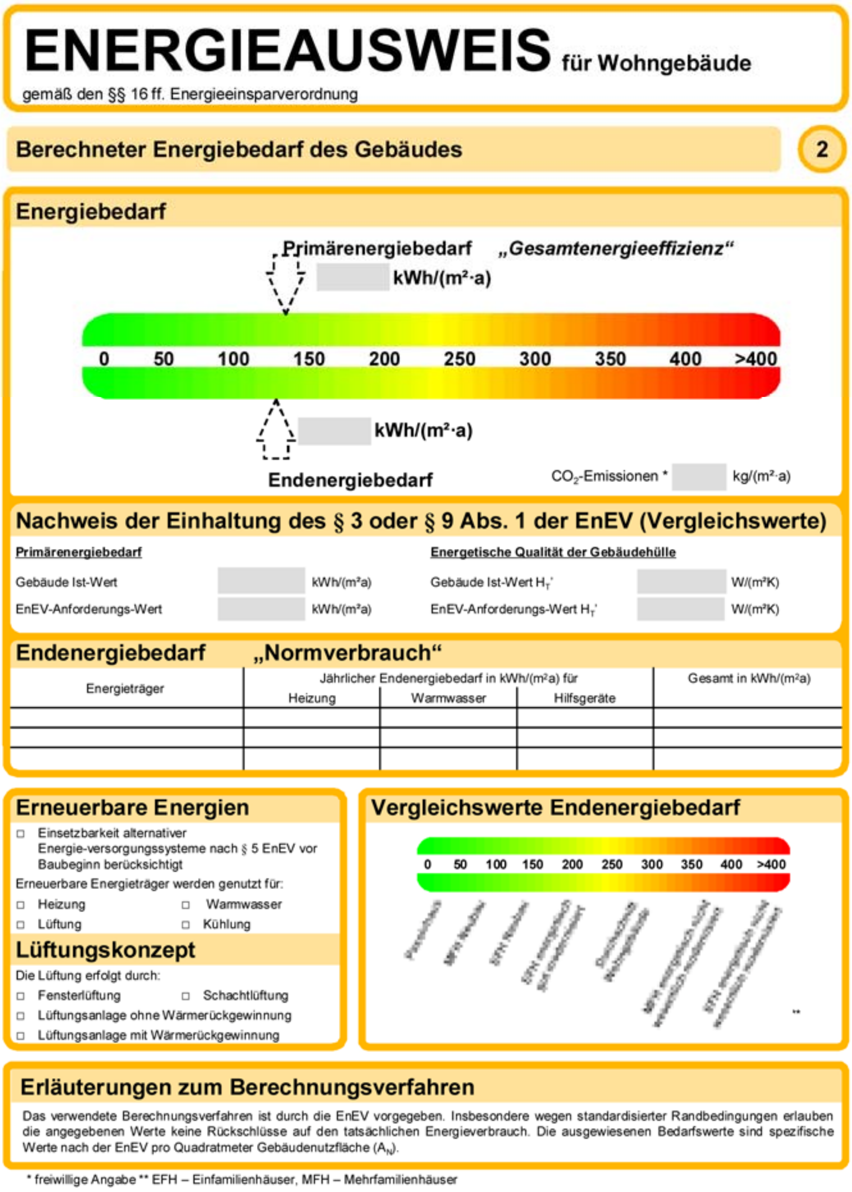
- Harmful substances (contained in building materials, released during use)
- Moisture (built-in moisture from the construction process, moisture generated during use)

These diverse tasks are fulfilled by numerous components and systems that are in general separately evaluated, labeled, and optimized. This scalar approach frequently leads to partial optima, but, however, not to an overall optimum. In part, it also produces contradictory statements. In many instances, only the investment costs for the insulation of the building or the heating system (and, for some time now, also the energy consumption during the use of the building) are used for the assessment. Other aspects, such as comfort, effects on performance, cleaning and maintenance costs and similar are not taken into account.

In addition, social and cultural functions must be fulfilled and aesthetic aspects must be considered. Quite often, these functions are not represented in a quantifiable assessment, although their importance may be dominant. This problematic situation makes the approach more difficult; consequently, it leads to a vectoral consideration with quantifiable “hard” and non quantifiable “soft” assessment quantities, with the inclusion of individual user wants and possibly the individual weighting of parameters.

2. Energy labeling of buildings

Now that the energy labelling of new buildings (and, in numerous cases, also of existing buildings) by means of an Energy Performance Certificate has been made obligatory by the Energy Saving Ordinance of 2007 (EnEV 2007) [1] - almost two decades after the first presentation [2] - an important element in the description of a building's quality can finally be considered to have been worked out. Now, the approach of a holistic building assessment should be adopted, which is to include as many further criteria as possible.


ENERGIEAUSWEIS für Wohngebäude

gemäß den §§ 16 ff. Energieeinsparverordnung

Berechneter Energiebedarf des Gebäudes 2

Energiebedarf

Primärenergiebedarf „Gesamtenergieeffizienz“

kWh/(m²·a)

0 50 100 150 200 250 300 350 400 >400

kWh/(m²·a)

Endenergiebedarf

CO_2-Emissionen * kg/(m²·a)

Nachweis der Einhaltung des § 3 oder § 9 Abs. 1 der EnEV (Vergleichswerte)

Primärenergiebedarf			Energetische Qualität der Gebäudehülle		
Gebäude Ist-Wert		kWh/(m²a)	Gebäude Ist-Wert H_T'		W/(m²K)
EnEV-Anforderungs-Wert		kWh/(m²a)	EnEV-Anforderungs-Wert H_T'		W/(m²K)

Endenergiebedarf „Normverbrauch“

Energieträger	Jährlicher Endenergiebedarf in kWh/(m²a) für			Gesamt in kWh/(m²a)
	Heizung	Warmwasser	Hilfsgeräte	

Erneuerbare Energien

- ☐ Einsetzbarkeit alternativer Energie-versorgungssysteme nach § 5 EnEV vor Baubeginn berücksichtigt

Erneuerbare Energieträger werden genutzt für:

- ☐ Heizung ☐ Warmwasser
- ☐ Lüftung ☐ Kühlung

Lüftungskonzept

Die Lüftung erfolgt durch:

- ☐ Fensterlüftung ☐ Schachtlüftung
- ☐ Lüftungsanlage ohne Wärmerückgewinnung
- ☐ Lüftungsanlage mit Wärmerückgewinnung

Vergleichswerte Endenergiebedarf

0 50 100 150 200 250 300 350 400 >400

**

Erläuterungen zum Berechnungsverfahren

Das verwendete Berechnungsverfahren ist durch die EnEV vorgegeben. Insbesondere wegen standardisierter Randbedingungen erlauben die angegebenen Werte keine Rückschlüsse auf den tatsächlichen Energieverbrauch. Die ausgewiesenen Bedarfswerte sind spezifische Werte nach der EnEV pro Quadratmeter Gebäudenutzfläche (A_N).

* freiwillige Angabe ** EFH – Einfamilienhäuser, MFH – Mehrfamilienhäuser

Figure 1. *Reproduction of the second page of the Energy Peformance Certificate for residential buildings (EnEV 2007) [7]*

3. Holistic labelling of buildings

A room-conditioning assessment vector (RcA vector) is suggested in [3] for at least the primary introduction of an overall holistic consideration of the “Room conditioning“ partial building function quantity. The principle structure of this vector is shown in Fig. 2.

From this and for each assessment criterion, the number of which can be very different according to the specific task, an objective assessment factor B will be introduced that can, however, be supplemented by an individual weighting factor W, so that the planner can better fulfill his particular wants and expectations in co-operation with the investor. The result is normalized to 1.

For the clear presentation of the complete vector, the form of a vectogram, as shown in Fig. 2, is suggested in [3]. This procedure enables any number of assessment criteria (which are if possible brought together in groups) to present the results obtained so that they are clearly and quickly recognizable, also allowing the comparison with alternatives. The definition and representation of reference curves from similar building projects simplifies the categorizing of the resulting solutions in respect to customary ones. Similarly, minimum standards can be pictured, as shown in Fig. 2.

The quality of a building can be clearly presented by the system described, which simplifies the processing of the flood of information. The task that is still to be done is therefore the definition of the criteria that are to be identified and the working out of methods for their objective assessment. For simpler implementation of the system, the designation “Sustainability Vector“, or “Building assessment vector” is suggested.

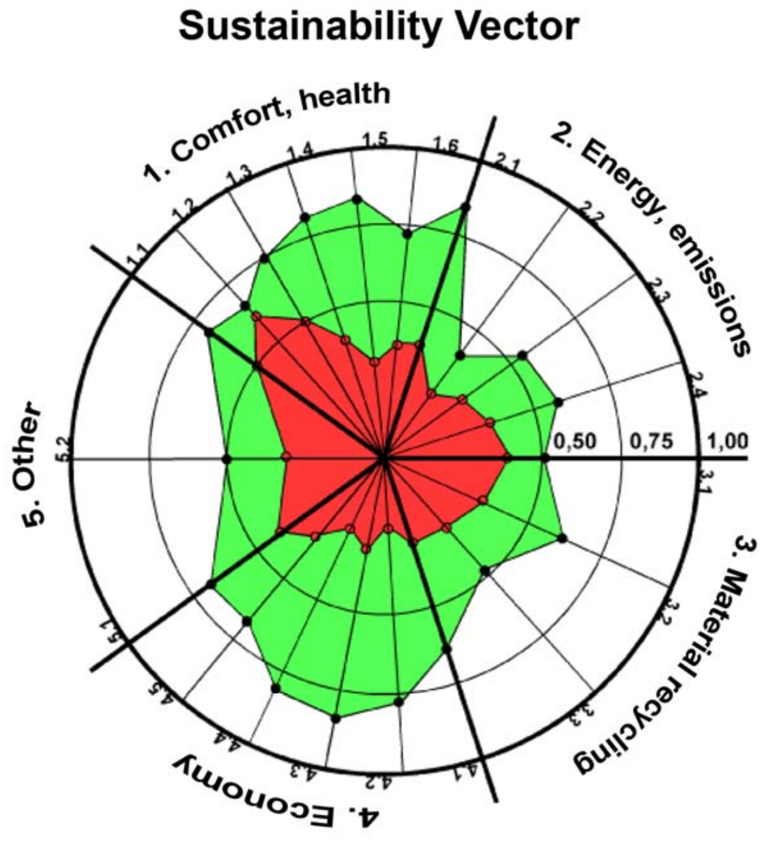


Figure 2. *Reproduction of the room conditioning assessment vector (RcA vector) suggested in [3], but named sustainability vector here.*

There are already several international approaches to holistic building assessment methods, such as, for example, the assessment tools:

- BREEAM: Building Research Establishment Environmental Assessment Method, GB
- LEED: Leadership in Energy and Environmental Design, USA
- DGNB: German Certificate for Sustainable Buildings, GER
- SBTool: Sustainable Building Tool (former GBTool), international
- CASBEE: Comprehensive Assessment System for Building Environment, JP
- EPIQR: Energy Performance Indoor Environmental Quality Retrofit, GER, FhG-IBP
- ÖÖB: Economic and Ecological Assessment, GER
- EcoPRO: Life-cycle Analysis, GER
- GaBi: Life-cycle Analysis, GER
- LEGEP Economic and Ecological Assessment, GER

An illustrative labeling prepared with the methods described above has already been introduced in some countries, but the methods used have deficits. Programmes and evaluation schemes have also been developed at a national level in recent years. They have not yet been completely established in the planning process, however, and deal only with partial aspects of the overall assessment. For example, the EPIQUR and ÖÖB programmes (which were developed in Germany and Europe) are only for new buildings or for existing ones; programmes such as LEGOE and sirADOS are limited to the ecological life-cycle analysis or to the purely economic point of view.

Against this background, the development of a holistic assessment tool for buildings, which includes procedures used in Germany and Europe for the assessment of energy efficiency, user comfort and many more, and additionally takes methods that are already internationally used into consideration, is of great importance. A label that can be successful in the market - the Energy Performance Certificate (that has now at last been introduced) could serve as a good example here - and which is agreed upon in close co-operation between all building participants, is not only necessary but would also promote the aspects of sustainability in the construction sector [4] [5].

For this reason, the BMVBS (German Federal Ministry of Transport, Building and Urban Affairs) established the “Round Table” several years ago. Here, experts first developed and then revised the “Guidelines for Sustainable Building“ [6]. In 2007, the “German Sustainable Building Council” (German abbreviation DGNB) was founded. The focus was on the following five protection goals for a certification system that is to be developed and is based on German environmental standards and environmental targets:

- Protection of resources
- Preservation of the natural environment
- Securing and preservation of worth
- Improvement in the surroundings and protection of public property
- Health and comfort of building users

With regard to the German Certificate for Sustainable Buildings (DGNB), it is becoming apparent that the following areas will flow into the assessment of the whole building performance:

- Ecological Quality
- Economic Quality
- Social-cultural and functional Quality
- Technical Quality
- Process Quality
- And Site Quality

These are presented in model shown in Fig. 3.

The individual areas on their part again comprise numerous criteria. Depending on the choice which criterion area is to be used 63 individual criteria are listed in Fig. 4.

From the author's point of view, a 3-column model would make good sense as, for example, the “Acoustic comfort“ criterion is listed under “Social, cultural and functional quality“ and so already covers the “Noise control“ aspect subsumed under “Technical Quality“, which makes the “Technical Quality” column unnecessary. Fire protection, for example, could be categorized under “Functionality“, and so on.

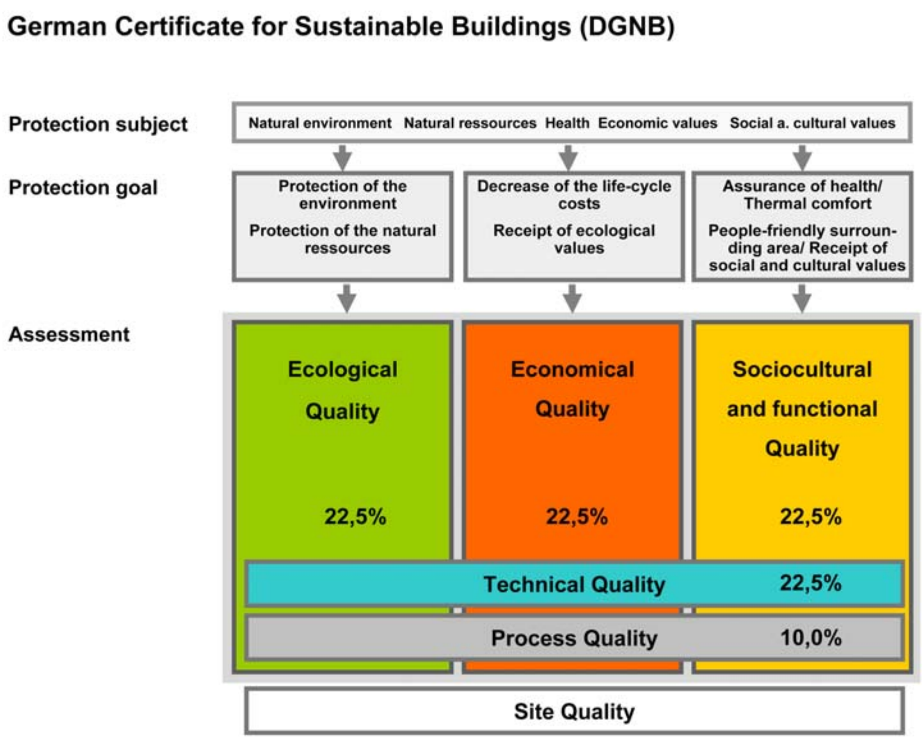


Figure 3. *Presentation of the “Sustainability pillars” worked out by BMVBS and DGNB*

Ecological Quality	**Effect on the local and global environment**	1.	Greenhouse potential (GWP)
		2.	Ozone-layer destruction potential (ODP)
		3.	Ozone generation potential (POCP)
		4.	Acidification potential (AP)
		5.	Eutrophication potential (EUT)
		6.	Risks for the local environment
		7.	Other effects on the local environment
		8.	Other effects on the global environment
		9.	Microclimate – Heat island effect
	Resource utilization and waste accumulation	10.	Primary energy demand, non-renewables
		11.	Primary energy demand, renewables
		12.	Other use of non-renewable resources
		13.	Waste
		14.	Drinking-water consumption
		15.	Land consumption
Economic Quality	**Life-cycle costs**	16.	Life-cycle costs (building-specific)
	Value performance	17.	Value stability
Socio-cultural and functional Quality	**Health, thermal comfort and user satisfaction**	18.	Thermal comfort in winter
		19.	Thermal comfort in summer
		20.	Indoor air quality
		21.	Acoustic comfort
		22.	Visual comfort
		23.	Exertion of influence (user)
		24.	Landscaping quality (building)
		25.	Safety and failure risks
	Functionality	26.	Barrier-free accessibility
		27.	Area efficiency
		28.	Conversion capability
		29.	Public accessibility
		30.	Bicycle comfort
	Design Quality	31.	Ensurement of design and urban quality through competition
		32.	Art in buildings
Technical	**Technical Quality**	33.	Fire protection

Quality		34.	Noise protection
		35.	Performance of the thermal and moisture protection of the building envelope
		36.	Back-up ability of technical facility equipment
		37.	Operability of technical facility equipment
		38.	Performance of technical facility equipment
		39.	Durability
		40.	Maintenance and repair friendliness of the construction
		41.	Resistance against hail, storm, high water
		42.	Deconstruction and recycling friendliness
Process Quality	**Construction Quality**	43.	Quality of the preliminary planning
		44.	Integrated planning
		45.	Proof of optimization and complexity of the approach in planning
		46.	Assurance of sustainability aspects in tender and placing
		47.	Creation of premises for optimal utilization and management
		48.	Construction site/ Construction progress
		49.	Quality of executive companies/ Pre-qualification
		50.	Quality assurance of building construction
		51.	Putting into service/ Briefing of the users
	Operating Quality	52.	Controlling
		53.	Management
		54.	Systematic inspection, maintenance and repair
		55.	Qualification of the operating personnel
Site Quality	**Site Quality**	56.	Risks at the micro-location
		57.	Loads/ Pollution at the micro-location
		58.	Image and condition of location and accomodation
		59.	Traffic connection
		60.	Nearness to usage-related objects and facilities
		61.	Adjacent media/ site development
		62.	Planning law situation
		63.	Expansion possibilities/ reserve assets

Figure 4. *Compilation of all individual criteria that are under discussion..*

It must be possible to quantify all criteria comprehensibly (hard criteria) or to describe them qualitatively according to uniform points of view (soft criteria). The form of a sustainability vector shown in Fig. 5 is suggested to enable a quick communication of the results to interested parties. The larger the particular area, the higher the sustainability of the building with respect to this criterion.

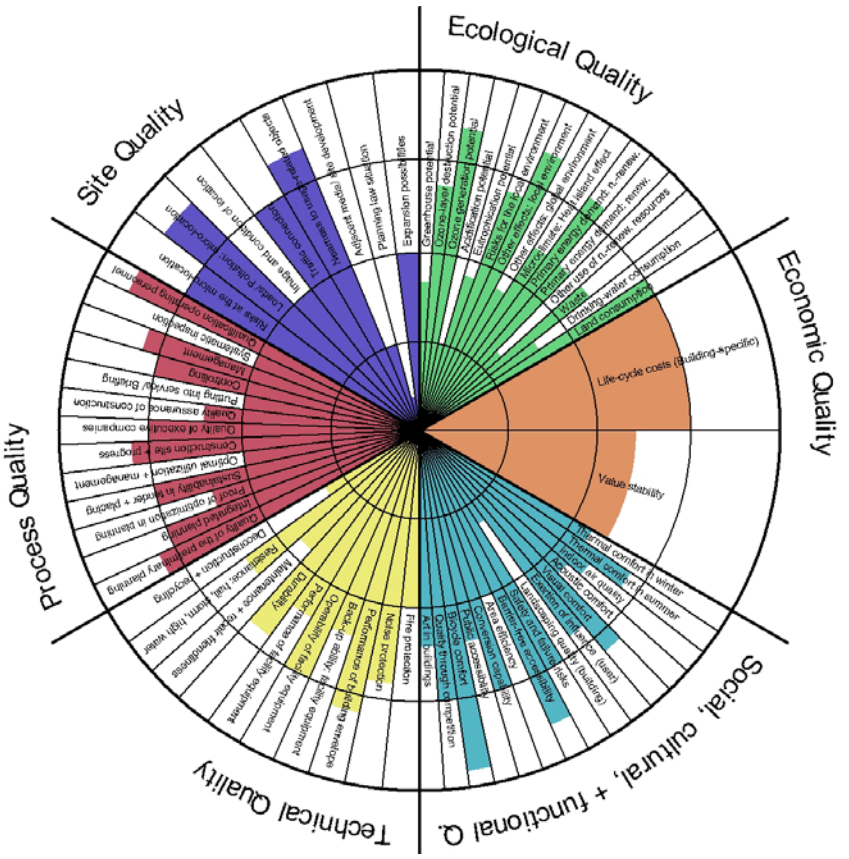


Figure 5. *Suggestion for a sustainability vector for clear identification of the sustainability of buildings.*

4. Added value and market chances of a holistic labelling

The Federal Ministry of Transport, Building and Urban Affairs (German abbreviation BMVBS) and the German Sustainable Building Council (German abbreviation DGNB), which was founded in 2007 in Stuttgart, are working now on a quality qualification for particularly environmentally friendly, healthy and resource-considerate buildings as the most important instrument for promoting sustained yield building. This new instrument for holistic building assessment takes up from agreements on international standardization and has as its motto, transparency and orientation to practice. Particularly important bases of information for the new system are quality for building products, the assessment of life cycle costs as well as environmental declarations on the basis of the ISO 14025 (EPD) international standard. The building assessment is based on an overview of the building and its life-cycle perspectives (50 years) as basis for efficient sustained yield building.

After testing the German Certificate during a pilot phase, 16 office buildings in Germany were certified with the German Certificate for Sustainable Buildings (Pilotversion 2008) in January 2009. Twelve building, which were in the planning and construction phase at this time, achieved the DGNB Pre-Certificate. One of the first certified projects was the Zentrum für Umweltbewußtes Bauen in Cassel (German abbreviation ZUB, *Center for ecological sensitive construction*) that was assessed with the silver certificate (Fig. 6).

Deutsches Gütesiegel Nachhaltiges Bauen

Figure 6. *Zentrum für Umweltbewußtes Bauen in Cassel (German abbreviation ZUB, Center for ecological sensitive construction): one of the first buildings in Germany which were certified with the German Certificate for Sustainable Buildings (DGNB)*

The German Certificate that is being worked on proves the maintenance of the sustainability criteria both to the owner of the building and to the user of it. The demand for environmentally conscious ecological products is continuously increasing and is resulting in an enormous market shift. Up to now there is very little knowledge on the purchased real estate and it is limited to a general description of the building. Extensive information is provided for lower value products, but such information is lacking with long-lived real estate, although it is more and more frequently asked for.

Not only the owner and the user of the building can profit from this, however, but also predominantly the German and European building industry, whose environmental competence is rated very highly in international comparisons. This strength should be acknowledged in the international market with the new quality qualification.

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The reuse management model of building steel structures

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Abstract

The reuse system mentioned in this paper is an overall system for realizing a reuse business in a cyclic process of design, fabrication, construction, maintenance, dismantling, and storage. For structural members to circulate as reusable members in the existing distribution system, two industries are needed: one responsible for production and product supply, which has already been established, and the other facilitating disposal, recycling, and reusing of the products resulting from the former. The authors define the former as the arterial industry, and the latter, as the venous industry, showing the size and importance of both industries. This paper shows CO_2 emissions of recycling and reusing in steel circulation process. Then, propose reuse management model of reusable members of building steel structures and consider its economic condition of reuse business through cost simulation.

Keywords: Environmental burden, Building steel structure, Reuse, Management model

1. Introduction

Japan has the technological potential to reduce its CO_2 emissions by 70 % compared to the 1990 level, while satisfying the expected demand for energy services in 2050 [1]. Nevertheless, CO_2 emissions in Japan have risen since 1990 in residential sector and commercial sector. Japan urgently needs to implement measures to reduce environmental burden [2-3].

As an architectural effort to reduce the global environmental burden, the authors have been pursuing studies on the evaluation of the environmental burden of building steel structures focusing attention on the amount of life cycle CO_2 emission, as well as on a system developed to facilitate reusing building steel structures through using information technology [4-6]. In order for reusable steel products to circulate in the existing distribution system, it is necessary to establish a venous industry, as opposed to an arterial industry which would be responsible for production and supply of newly manufactured members. This venous industry is to facilitate the disposal, recycling and reusing of the products resulting from the arterial industry.

Extending building service life is the most crucial element in reducing the environmental burden of building steel structures. Nevertheless, there are a number of buildings that should be demolished for physical, architectural, economic, and social reasons. The reuse of entire buildings, or at least reuse at the structural member level, is extremely effective for limited-term and short-life buildings that are beginning to find demand. Scrapping steel structural members requires energy for melting, and this melting process causes substantial CO_2 emissions. Meanwhile, reusing structural members requires only ancillary energy for dismantling, transportation, and adjustments, causing less environmental burden.

This paper proposes a reuse management model for reusing building steel structures using information technology. Taking a mid-rise steel-framed structure (apartment housing) using reusable members as an example, the authors perform a cost simulation and examine the profit standard for reuse management model.

2. Reuse System

The reuse system is an overall system for realizing a reuse business in a cyclic process of design, fabrication, construction, maintenance, dismantling, and storage. When promoting reuse of general steel structures, it is indispensable to take a cross sectional view of the construction industry and to make full use of information technology via the Internet. With respect to this, based on the proposed business management model, we would like to set out a pathway towards creating a database containing information on structural members of building steel structures, ultimately realizing the reuse of structural members.

2.1 Reuse Flow

A reuse flow diagram of the building steel structure is presented in Figure 1. The dotted line shows the information flow and the continuous line shows the flow of reusable members. Reusable members circulate via the database (DB) through a cyclic process: design, fabrication, construction, maintenance, dismantling, and storage.

2.2 Reuse management model

In order that the reuse management industry is economically viable, the authors propose the model presented in Figure 2. (hereinafter referred to as the reuse management model). This model consists of three fields: management, design, and stock. The role of information in the reuse business can be clarified by characterizing refuse flow in these three fields, which facilitates creation of the DB. Business management, which occupies a central position in the reuse management model, involves managing the reuse business as well as controlling information technology engineering(hereinafter referred to as the IT engineering) and fabricators of reusable members. IT engineering is responsible for evaluating the performance of reusable members; it creates a system for unified management of information on reusable members, and builds and maintains the DB on the performance of reusable members. The reuse system is provided on the Internet to give DB access to an unlimited number of structural designers and other users. The information on reusable members in the DB is constantly updated. Fabricators of reusable members are responsible for fabricating and storing reusable members. They also test the quality of reusable members, and register all relevant information in the DB of reusable members maintained by IT engineering.

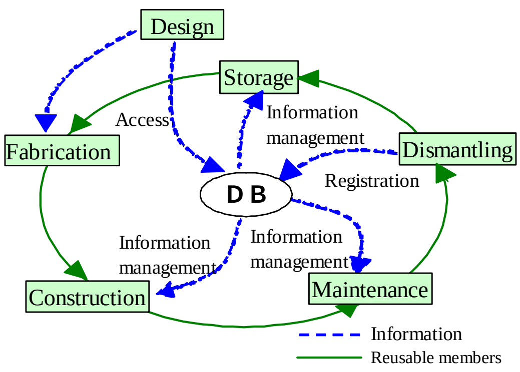


Figure 1. *Reuse flow*

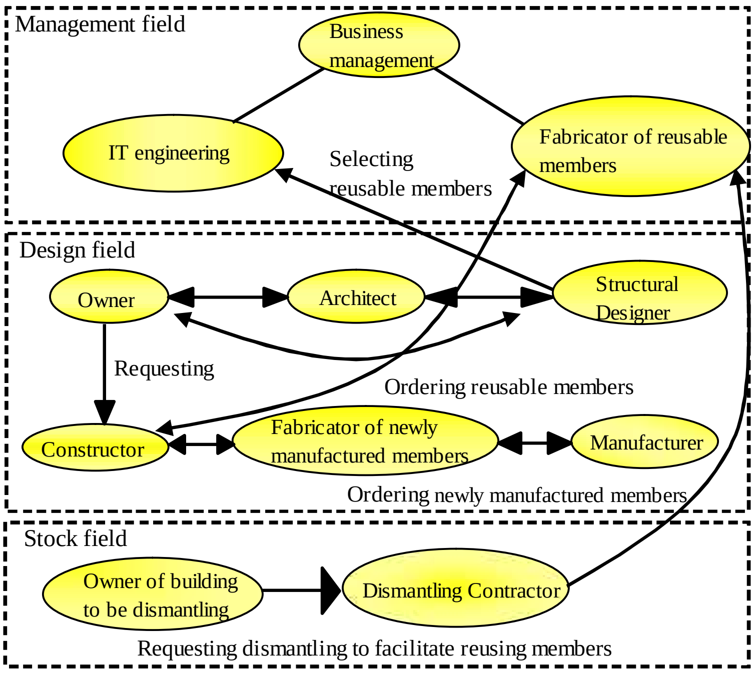


Figure 2. *Reuse management model*

These processes described above are collectively characterized as part of the management field.

In the design field, the architect designs a building in response to the owner's requests, and the structural designer selects the structural members. In the process of selecting the members, the structural designer decides if reusable members could be used. When it is decided to use reusable members, the structural designer accesses the DB managed by IT engineering to select appropriate reusable members. During the construction stage, the constructor, based on drawings and specifications, can order both reusable members and newly manufactured members. Newly manufactured members are manufactured and supplied. The constructor should obtain prior consent from the owner and designer of the building to use newly manufactured members if reusable members are unavailable due to changes in the design or changes in the demolition timing of target buildings from which reusable members are expected. Thus, in the design field, fabricators of members can fabricate reusable members in addition to newly manufactured members, increasing business options available to them.

In the stock field, reuse dismantling and sorting is necessary in order to use structural members as reusable members. After reuse dismantling, the members collected for use as reusable members are inspected for their quality and kept in the responsible fabrication storage. The performance data of the reusable members kept in storage is registered in the DB managed by IT engineering. Business management obtains complete data on the buildings from which reusable members are expected, including the construction sites, demolition timing, and quantity of structural members. Business management can then comprehensively determine economically efficient use of reusable members based on knowledge of reusable member storage sites: this is a process in the stock field. DB utilization concerning the performance of target building steel structures provides owners with increased business options.

2.3 CO_2 emissions of reusing and recycling

The diagram in Figure 3 shows CO_2 emissions of steel circulation process. Steel products used as newly manufactured members such as rolled H-section steels are manufactured through several processes including blast furnace, basic-oxygen furnace, continuous casting and rolling. After buildings are demolished, products used for the buildings are collected and scrapped. According to past studies [7-8], Average CO_2 emissions($W_{recycling}$) of recycling basic-oxygen furnace steel and electric arc furnace steel during their life cycle is as follows:

$$W_{recycling} = \frac{A + \gamma_1 B + \gamma_1 \gamma_2 B + \gamma_1 \gamma_2 \gamma_3 B + \gamma_1 \gamma_2 \gamma_3 \gamma_4 B + \cdots + \gamma_1 \gamma_2 \gamma_3 \gamma_4 \cdots \gamma_i B}{1 + \gamma_1 + \gamma_2 + \gamma_3 + \gamma_4 + \cdots + \gamma_i} \quad 1)$$

Here,

$A = P1 + P2 + P3 + P4 + P5$, $B = P6 + P7 + P8 + P9$

i (=1-m): The number of recycling circulations

P 1, *P* 2, *P* 3, *P* 4, *P* 5: CO_2 emissions in individual processes of raw material extraction and transportation, blast furnace, basic-oxygen furnace, continuous casting and rolling defined zone A.

P 6, *P* 7, *P* 8, *P* 9: CO_2 emissions in individual processes of recovery and primary treatment, electric arc furnace, continuous casting, and rolling defined zone B.

γ_i : recycling ratio at *i*-th *i (=1-m)*: Number of recycling circulations

γ_1: Recovered scrap used during basic-oxygen furnace steel production.

$\gamma_{2\sim m}$: Recovered scrap used during electric arc furnace steel production.

As recycling ratio of each process is assumed to be constant, equation 2) can be found by equation 1).

$$W_{recycling} = (A + B\sum_{i=1}^{m}\gamma_i) / (1 + \sum_{i=1}^{m}\gamma_i) \quad 2)$$

Average CO_2 emissions ($W_{reusing}$) of reusing can be found by equation 3) as well as recycling.

$$W_{reusing} = (A + C\sum_{j=1}^{n}\gamma_j) / (1 + \sum_{j=1}^{n}\gamma_j) \quad 3)$$

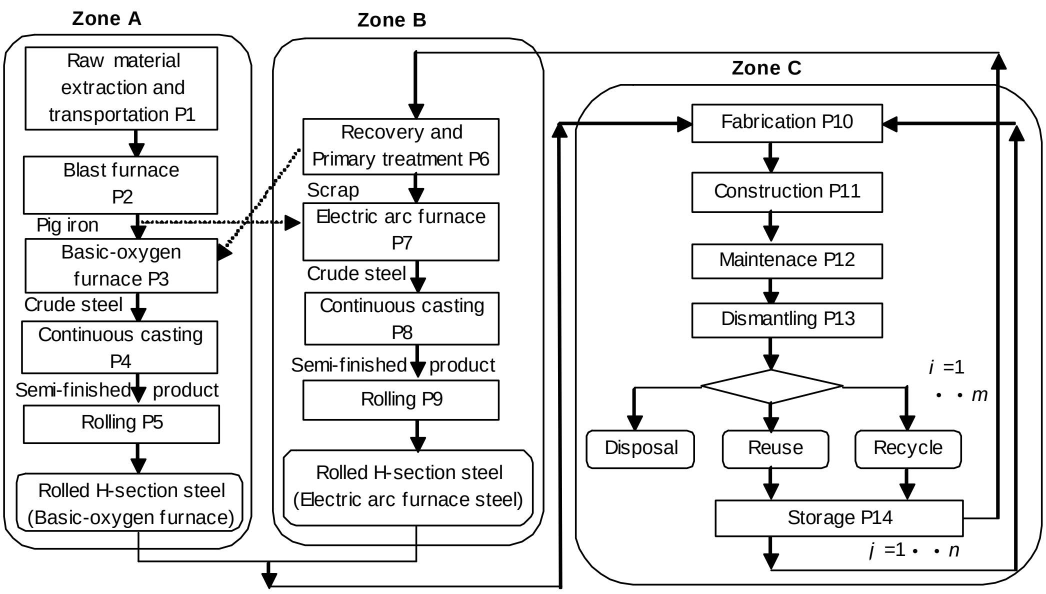


Figure 3. CO_2 emissions of *steel circulation process*

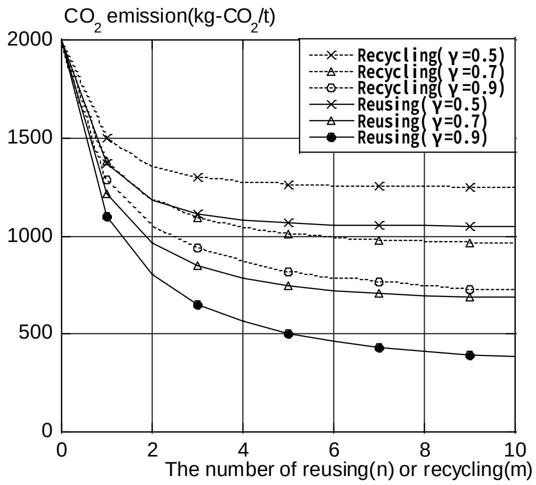


Figure 4. *CO_2 emissions of recycling and reusing*

Here,

C=P10+P11+P12+P13+P14

P10,P11,P12,P13,P14: CO_2 emissions in individual processes of fabrication, construction, maintenance, dismantling, storage including transportation defined zone C

$W_{reusing}$: CO_2 emissions of reusing

γ_j : Reusing ratio at *j* (0.5-0.9)

j (=1-n): Number of reusing circulations

Figure 4. shows the average CO_2 emissions (kg-CO_2 / t) from recycling and reusing. Here, CO_2 emissions are assumed to be 2000kg-CO_2 / t from P1 to P5, and 500kg-CO_2 / t from P6 to P9, 100kg-CO_2 / t from P10 to P14. Although the recycling ratio varies depending on the type of basic-oxygen furnace and electric arc furnace steel products, the intended use, and import/export, average CO_2 emissions were calculated assuming that a recycling ratio γ_i = 0.5-0.9. To compare reusing with recycling, a reusing ratio is assumed to be γ_i =0.5-0.9. The calculation results indicate that CO_2 emissions of recycling and reusing are reduced, as the average number of circulations increases, the use of newly manufactured members decreases. When the number of recycling or reusing circulations is one(γ =0.9), CO_2 emissions of them are 1290 kg-CO_2/t, 1100 kg-CO_2 / t respectively. According to past study, reusable members of rolled-H steel are approximately assumed to be 1 million tons per year in Japan [9]. In this case if 1 million tons per year of rolled H-section steels can be used as reusable members with one circulation, 0.9 million tons per year of CO_2 emissions can be reduced. If these rolled H-section steels are to be recycled with one circulation(γ= 0.9), approximately 0.7 million tons per year of CO_2 emissions can be reduced. Namely, when the number of recycling and reusing circulations is one, CO_2 emissions of them are reduced approximately 35 %, 45 % respectively, comparing to using all newly manufactured members.

3. Economic efficiency of reuse business

3.1 Construction cost

The construction cost is set based on the references, as shown in Tables 1 and 2. Reuse management is responsible for managing and operating the database. Fabricator of reusable member or stock management is responsible for attaching IC tags. Parameters used in cost simulation include the proportion of reusable members that can be collected from demolition materials, the proportions of reusable and newly manufactured members to be used in construction, and the extent of fabrication. Multiple models are created in which the proportion of use of reusable members obtained from demolition materials, the extent of fabrication, and the proportion of reusable members used for construction are respectively set at 10 % intervals. These models thus created are combined to set up 1221 cost simulation cases. The newly manufactured members mentioned here refer to products manufactured in a blast furnace or electric arc furnace, and include recyclable members. Among the models created for the purpose of cost simulation are those in which 100 % of members collected from demolition are recycled and 100 % of members are reused in construction, although impossible in practice. The relationship between the parameters and cost is multiple, but is assumed to be linear for simplicity. In the arterial industry, steel-framed structures are demolished to generate recyclable materials, which are sold as scrap. In the stage of producing crude steel from scrap metal, circulatory elements, such as tin and copper, are mixed into the steel. For this reason, increasing the number of recycling cycles of the same material can cause quality loss. Here, however, it is assumed that such quality loss of recycled members

Table 1. *Construction cost*

Detail \ Construction cost		Newly manufactured members Dollars / t	Reusable members with fabrication in use Dollars / t	Reusable members without fabrication in use Dollars / t
Material cost		700	350	350
Storage cost		0	100	100
Database creation cost		0	100	100
Transportation cost	Manufacturer to fabricator	50	--	--
	Storage to Fabricator	--	50	0
	Fabricator to Constuctor	100	100	--
	Storage to Constructor	--	--	100
	Constructor to storage	--	50	50
Fabrication cost		650	450	0
Erection cost		250	250	250
Temporary work cost		250	250	250
Total cost		2,000	1,700	1,200

Note 1: Transportation cost varies depending on the volume of stock, regionality, and storage site, but average values for short and long distances are shown here.

Note 2: Fabrication cost of reusable members varies depending on the extent of fabrication, but average values are shown here.

Table 2. *Dismantling and demolition cost*

Details \ Methods	Reuse dismantling Dollars / t	Conventional demolition Dollars / t
Temporary work cost	250	125
Reuse dismantling cost	250	--
Conventional demolition cost	--	125
Cost of selling steel members	-350	-100
Total cost	150	150

does not occur.

Common conditions:

- Obtaining less damaged members through reuse dismantling.

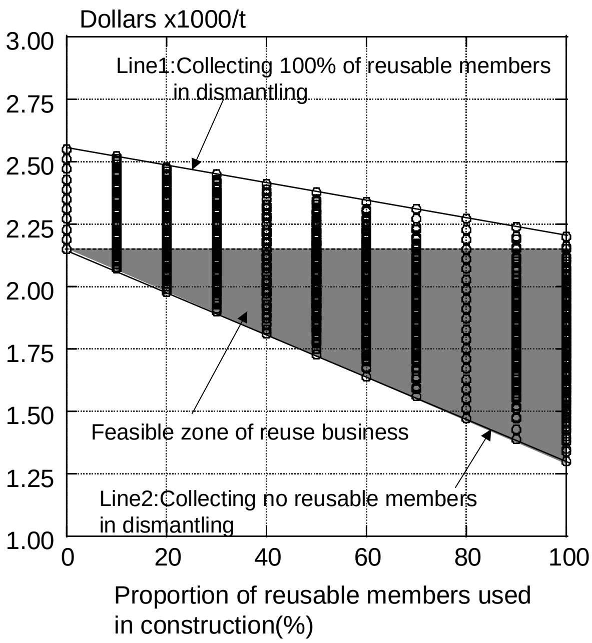
- The performance of reusable members can be maintained through adequate rust prevention measures.

- The length of reusable members can be adjusted by welding and cutting in the fabrication stage.

- The number of uses of reusable members is set at 1, considering the durability of IC tags and the storage period of reusable members. The influence of cost fluctuations of reusable members in construction and cost fluctuations of demolition materials in demolition are excluded.

3.2 The feasible zone of the reuse business

Figure 5 shows the relationship between the cost and the proportion of reusable members used in construction. The horizontal axis represents the proportion of reusable members used in construction, and the longitudinal axis, the cost associated with one cycle from construction to demolition. For example, when equal quantities of reusable and newly manufactured members are used, the cost per cycle is approximately 1800 dollars/t for conventional demolition, and approximately 2400 dollars/t for reuse dismantling. The cost per cycle is 2150 dollars/t when conventional demolition methods are executed and newly manufactured members are used for the entire amount for construction. Line 1 in



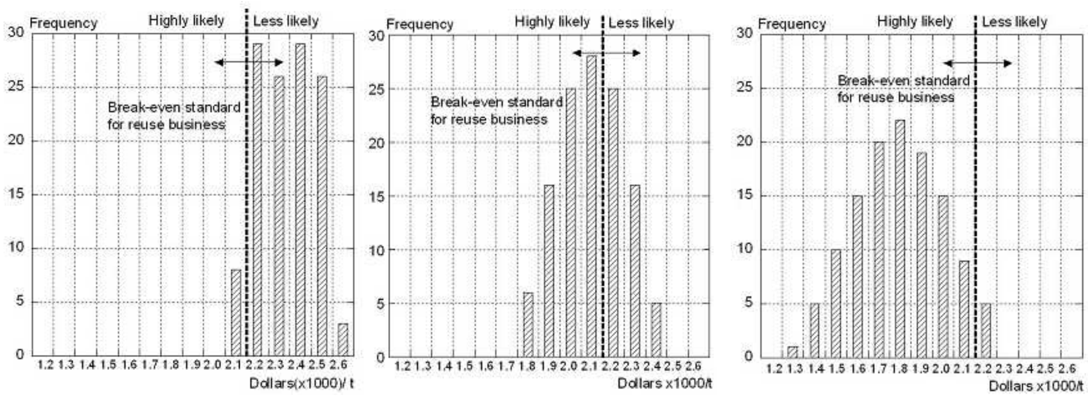
Note: When reusable members are not collected in dismantling, all members are assumed to be recycled. Now, however, several % of all members are not recycled but scrapped.

Figure 5. *Proportion and cost of reusable members used in construction*

Figure 5. represents the cost per cycle when all reusable members are collected during dismantling. Line 1 is formed by connecting the cost when reusable members are not used in construction (2550 dollars/t: the sum of the costs of newly manufactured members at 2000 dollars/t and reuse dismantling at 550 dollars/t) and the cost when all reusable members are used in construction (2200 dollars/t: the sum of the costs of newly manufactured members at 1650 dollars/t and reuse dismantling at 550 dollars/t). Line 2 represents the cost per cycle when reusable members are not collected during demolition (100 % recyclable materials). It is formed by connecting the cost when reusable members are not used in construction (2150 dollars/t: the sum of the costs of newly manufactured members at 2000 dollars/t and conventional demolition at 150 dollars/t) and the cost when all reusable members are used in construction (1300 dollars/t: the sum of the costs of newly manufactured members at 1150 dollars/t and conventional demolition at 150 dollars/t). The latter describes the current steel distribution system and an already established recycling business.

The area indicated by hatching in Figure 5. indicates the zone where reuse business is feasible, which is the zone where the cost of using reusable members in construction falls below that of using all newly manufactured members in construction. As can be seen in Figure 5, the zone expands with increasing use of reusable members. As is often the case in the current steel distribution system, newly manufactured members are purchased for construction and sold as recyclable materials after demolition. This figure indicates that in order for reuse business to be feasible, it is necessary to set the proportions of reusable members and newly manufactured members used in construction, as well as the extent of reuse fabrication so that the overall cost falls within the hatching zone.

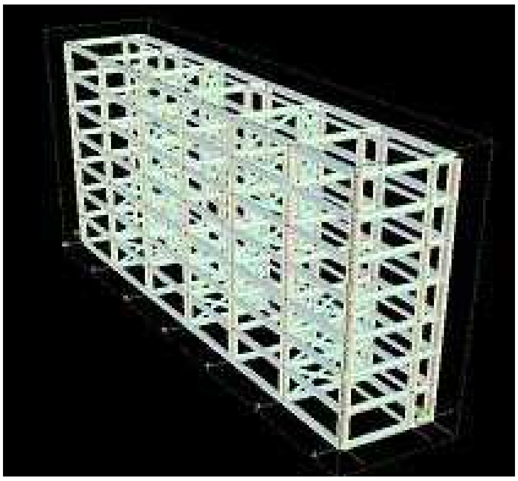
Histograms showing the different proportions (10 %, 50 % and 100 %) of reusable members used in construction are presented in Figure 6. The horizontal axis represents the cost of



(a)10% in use (b)50% in use (c)100% in use

Figure 6. *Proportions of reusable members used and frequency*

one cycle from construction to dismantling. The longitudinal axis represents the frequency of business obtained among the simulation models (1221 cases). As can be seen in the histograms, when the use proportions of reusable and recyclable members are equal, the distribution closely approximates normal distribution. When recyclable members are used for the total amount, as the proportion of reusable member use increases, the normal distribution moves to the left side of the profit standard of the reuse business. This indicates that the proportion of reusable members needs to be increased to over 50 %. For reuse business continuity, business feasibility is improved by increasing the proportion of reusable members. In the view point of procuring resource and to secure a steady supply of reusable members used in construction, generating a great volume of reusable members during dismantling is executed.



Specification :

Building area:588m^2

Floor area:4029m^2

Number of stories: 7

Story height :

Distance of column in X,Y direction :6.0 m (6 spans),7.5 m, 4.6 m (2 spans)

Figure 7. *Mid-rise steel-framed building*

3.3 Cost simulation

Figure 7. presents a model (apartment housing) constructed utilizing reusable members for a two-way rigid frame structure used in a mid-rise steel－framed building structure with a building area of 588 m^2, floor area of 4,029 m^2, and seven stories. Structural members used include columns (H: 350-800) and beams (H: 250-500). These members are assumed to be collected from a one-story steel-framed building. Cost simulation was performed on a mid-rise steel-framed structure based on the

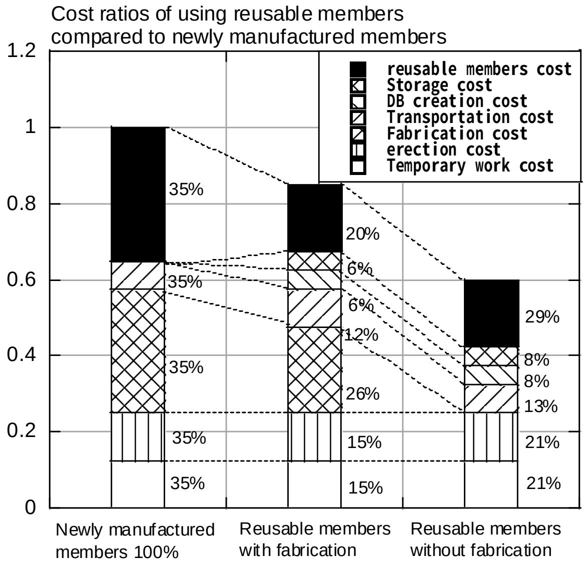


Figure 8. *Cost comparison*

relationship between the cost and proportion of reusable members used in construction as described in the foregoing section 3.2. The simulation assumes that methods permitting reuse dismantling and relocation have already been established. It is also assumed that by taking adequate rust prevention, the performance of reusable members can be maintained, and that there is a large stock of reusable members. In addition, it is assumed that the length of reusable members can be altered by welding and cutting in the fabrication stage. Newly manufactured members, reusable members with fabrication and those without fabrication are presented. Here, first it means all newly manufactured members are used without reusable members. Secondly it means reusable members that require refabrication at the factory without newly manufactured members. Thirdly, it means reusable members that do not only require refabrication at the factory but also on-site slightly without newly manufactured members. Figure 8. shows that economic efficiency increases as refabrication of reusable members decreases. Using all reusable members that require refabrication reduces costs by 15 % and using all reusable members that do not require refabrication reduces costs by 40 %, comparing to using all newly manufactured members.

4. Conclusions

This paper showed CO_2 emissions of recycling and reusing in steel circulation process. Then, proposed the reuse management model of building steel structures using information technology and performed cost simulation on a mid-rise steel-framed structure (apartment housing). Presented below are the findings obtained from the simulation:

1) Considering the reuse flow, the reuse management model consists of the management field, new design field, and stock field.

2) When the number of recycling or reusing circulations is one (γ= 0.9), CO_2 emissions of them are reduced approximately 35 %, 45 % respectively, comparing to using all newly manufactured members.

3) Based on the simulation results, the zone where reuse business can be feasible is shown. For reuse business continuity, business feasibility is improved by increasing the proportion of reusable members.

4) In the mid-rise steel-framed structure model, when a large stock of reusable members is available, a 15 % cost reduction is possible by using all reusable members that require refabrication and a 40 % cost reduction by using all reusable members that do not require refabrication comparing to using all newly manufactured members.

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Studying the correlation among performance related parameters of ordinary and high strength semi-lightweight concretes

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Abstract

Recently the main trend of concrete materials research is directed to change the application of the in-used prescriptive recommendations to the performance-based models. This scope requires development of codes and standards including different types of predictive models showing as close as possible the real behavior of concrete, although there are many restrictions to model concrete properties precisely. Reinforced concrete corrosion is the main deterioration problem in many countries. To have some idea about concrete corrosion rate and extent it is required to know the pore structure and ionic environment of concrete.

In this paper it is tried to study three different performance-based parameters of ordinary and high strength concretes produced by natural and semi-lightweight aggregates. Concrete electrical resistivity, sorptivity and compressive strength are compared to model the chloride ingress profiles in different types of concretes. These parameters are easy to be measured and propose some performance characteristics of concrete not only from structural point of view but also from durability performance aspects. This paper shows that by a systematic manner it is possible to find and select the best parameters in studying the concrete performance in corrosive environments.

Keywords: Concrete performance, corrosion, electrical resistivity, sorptivity, chloride ingress profile model

1. Introduction

Aging, material deterioration, and environmental impacts are main reasons for concrete structures to be encountered with many problems including lack of durability and decreasing load bearing capacity. Advancing in the new world needs building important structures such as nuclear plants and offshore facilities in aggressive environments. The main concrete deterioration type that exists almost in any country is concrete corrosion [1–3]. Chloride ion ingress in concrete which leads to the progressive corrosion has the most important effect in maintenance and repair plans for concrete structures. The economical conditions force the decision-makers to develop some tools for better understanding the problems and then prediction of service life of structures. Service life prediction is important from two points of view: for new structures to be designed and for existing structures. Although there are different types of concrete deteriorations, corrosion is considered for the service life predictions in many researches and under-developing design codes [1]. The essential scope of these codes is to use some models which help the designers to have insights about the material and structural performances. Performance-based design is almost an innovative area in concrete structural design. Most of the existing models have some inputs which show the concrete mix parameters such as water-to-cementitious materials ratio, binder content and so forth. But it seems it is better to have some other tools to measure special properties of concrete which are more related to the real performance. Practically they should be also easy to be determined. In this paper among many performance–based parameters of concrete electrical resistivity, sorptivity and compressive strength are studied and compared to model the chloride ingress profile in different type of concretes with natural and semi-lightweight aggregates.

In general, there must be a movement of chlorides into concrete to start the corrosion. This movement of chlorides can be represented by a chloride front, which, if monitored in relation to the position of the reinforcement, will provide an indication of the durability of a structure and hence service life prediction of reinforced concrete structures. There is always a threshold amount of chloride ions which leads to depassivation of the reinforcement. The determination of the chloride profile involves removing of concrete samples from various depths and plotting the chloride content against the depth [4]. It needs a cumbersome and sometimes expensive experimental work. Therefore in this paper it is tried to propose a model for chloride content against the depth based on the comparison of the test results for concrete performance-based properties as mentioned above. It should be declared that at this stage modeling is only based on the results of accelerated tests for chloride ion ingress in concrete. It will be the next stage of this research work to correlate the long term test results with the accelerated data when they become available. Therefore the current model introduced in this paper can be used by designers only to compare various concrete mixes from service life prediction point of view.

2. Experimental program

Concrete mixes containing two types of aggregates (natural (NA) and semi-lightweight (LA)), three water-to-cementitious materials ratios (w/(c+csf) = 0.35, 0.40 and 0.45), two cement contents (c+csf = 350 and 400 kg/m^3) with three condensed silica fume substitution ratios (c/(c+csf) = 0, 0.07 and 0.10) were used.

Proportioning of coarse and fine aggregates of 36 different concrete mixes was obtained for unit weight of 2400 and 2100 kg/m^3 for ordinary and semi-lightweight concretes, respectively. Slump range was 9-12 cm. All specimens were cured in water for 28 days. For each concrete mixes two cylindrical specimens were made for compressive strength and electrical resistivity measurements and two 10-centimeter cubes for sorptivity tests.

In the case of chloride ion ingress test thirty six 10-centimeter diameter cylinders were made for 1-D diffusion.

After 28 days specimens were removed from water to reach to the saturated-surface-dry condition.

At first electrical resistivity of each concrete mix was measured by a 4-point Wenner array electrical resistivity device.

Then concrete mix sorptivity tests were conducted after stabilizing cube weights to a constant quantity at 40 Celsius temperature in oven.

Concrete is a multi-component, micro-porous, microstructure-sensitive construction material, which provides the channels for fluid flow and ion transport [5]. Since conventional chloride diffusion test for concrete is time-consuming, an effective electrochemical method is to apply an external electrical field for accelerating chloride penetration [6]. In this research work the accelerated chloride ions ingress test method which is an electrochemical type was developed. It was decided to have more acceleration by using high concentration sodium chloride (NaCl) solution with high voltage electrical current. For all test series, the chloride 1-D ingress in concrete process was accelerated by 1-molar sodium chloride (NaCl) solution together with 60 volts electrical current. Acceleration duration was 28 days. After 28 days concrete specimens were dried and drilled to some depths to prepare the necessary amounts of powder for free chloride concentration tests. Since there were many concrete mixes with very small electrical diffusivities only few centimeter depths were needed for chloride concentration measurements.

The results for all mixtures show that the accelerated chloride ion ingress test with relatively high-voltage electrical current and high concentration sodium chloride (NaCl) solution is capable of showing chloride ion ingress process in concrete during 28 days which is equivalent to some years in real exposures. At this time it is not found what the equivalent real time chloride ion ingress in concrete is to get same results for the 28 days in accelerated test but the trends show the suitability and applicability of the test method for comparison of durability requirements in the design stage. The calibration factor of real exposure to accelerated test will be found in next steps of this research work.

Table 1 summarizes all test results. Figure 1 shows a typical test result of chloride ion ingress profile in concrete.

Table 1. *Test results for 36 different concrete mixes*

Concrete Mix	Compressive Strength (N/mm^2)	Electrical Resistivity (kΩ-cm)	Sorptivity $(mm)/t^{0.5}$	Concrete Mix	Compressive Strength (N/mm^2)	Electrical Resistivity (kΩ-cm)	Sorptivity $(mm)/t^{0.5}$
NA-0.35-350-0%	37.0	11.3	0.00001	**LA-0.35-350-0%**	25.6	8.0	0.00002
NA-0.35-400-0%	55.4	8.4	0.00002	**LA-0.35-400-0%**	24.4	7.3	0.00002
NA-0.40-350-0%	45.8	8.0	0.00003	**LA-0.40-350-0%**	29.6	8.2	0.00002
NA-0.40-400-0%	38.7	7.0	0.00002	**LA-0.40-400-0%**	23.8	7.3	0.00002
NA-0.45-350-0%	33.6	6.5	0.00004	**LA-0.45-350-0%**	23.5	7.0	0.00003
NA-0.45-400-0%	46.3	5.5	0.00003	**LA-0.45-400-0%**	28.0	5.9	0.00005
NA-0.35-350-7%	57.3	13.0	0.00001	**LA-0.35-350-7%**	35.3	13.0	0.00001
NA-0.35-400-7%	52.0	13.0	0.00002	**LA-0.35-400-7%**	31.3	13.0	0.00002
NA-0.40-350-7%	49.2	12.0	0.00001	**LA-0.40-350-7%**	32.2	10.7	0.00002
NA-0.40-400-7%	48.3	9.5	0.00002	**LA-0.40-400-7%**	29.2	7.0	0.00002
NA-0.45-350-7%	33.5	7.9	0.00002	**LA-0.45-350-7%**	25.8	9.5	0.00002
NA-0.45-400-7%	41.0	7.8	0.00002	**LA-0.45-400-7%**	27.9	8.3	0.00002
NA-0.35-350-10%	50.7	21.0	0.00001	**LA-0.35-350-10%**	40.8	17.3	0.00002
NA-0.35-400-10%	49.0	15.0	0.00001	**LA-0.35-400-10%**	40.0	17.0	0.00002
NA-0.40-350-10%	42.5	14.5	0.00002	**LA-0.40-350-10%**	32.1	16.3	0.00002
NA-0.40-400-10%	52.5	14.0	0.00002	**LA-0.40-400-10%**	37.7	15.0	0.00002
NA-0.45-350-10%	33.2	12.3	0.00002	**LA-0.45-350-10%**	29.7	11.3	0.00003
NA-0.45-400-10%	38.3	12.0	0.00002	**LA-0.45-400-10%**	31.8	11.0	0.00003

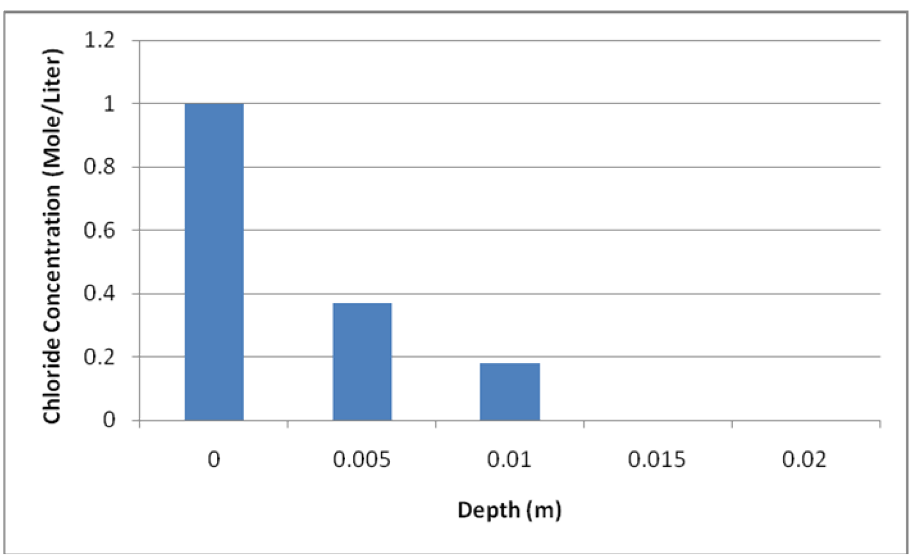

Figure 1. *Typical test result of chloride ion profile for concrete mix LN-0.45-350-0%*

3. Chloride ion ingress profile modeling

The scope of this paper is to model the chloride ion ingress profile. This profile shows two important characteristics for the design and construction of concrete structures: the resistance to and the initial rate of chloride penetration in concrete [7]. These parameters are useful for decision making by comparison of predicted service life of reinforced concrete structures with different concrete mixes.

In many research works Fick's 2nd law is used to model the chloride ion ingress in concrete [7]. Most of the researchers use the following partial differential equation which shows the diffusion process:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}(D\frac{\partial C}{\partial x}) \quad (1)$$

where,

C = chloride ion concentration (Mole/Liter),

x = depth (m),

t = time (s) and

D = diffusion coefficient (m*m/s)

By applying boundary and initial conditions for semi-infinite concrete and assuming constant D the solution of Eq. (1) is:

$$C(x,t) = C_s\left[1 - erf(\frac{x}{\sqrt{4Dt}})\right] \quad (2)$$

where,

Cs = Chloride ion concentration at surface (C(0,t)), (Mole/Liter).

Although the trace of this method and model can be found in literature, test results show that the chloride ion ingress process in concrete is a complex phenomenon. Complexity arise from non-constant diffusion coefficient, concrete aging and environmental condition effects on the process [7].

Based on this fact in this paper the descending exponential function is applied in modeling the chloride ion ingress profile in concrete. It is more capable to be fitted by experimental results comparing to the Eq. (2). The descending exponential function form is:

$$C(x) = e^{-f(z)} \tag{3}$$

Exponent f(z) consists of a function with independent variable z. Here z can be a candidate of any mentioned 3 concrete performance-based parameters: electrical resistivity (ER), sorptivity (S) and compressive strength (CS). At first regression analysis was applied to find the constant exponent for each concrete mix. Table 2 shows the results.

Table 2. *Regression analysis results for finding f(z) = constant from chloride ion ingress tests for different concrete mixes*

Concrete Mix	Chloride Profile Exponent	R^2	Concrete Mix	Chloride Profile Exponent	R^2
NA-0.35-350-0%	572	0.994	**LA-0.35-350-0%**	526	0.994
NA-0.35-400-0%	542	0.994	**LA-0.35-400-0%**	526	0.994
NA-0.40-350-0%	430	0.989	**LA-0.40-350-0%**	434	0.990
NA-0.40-400-0%	395	0.988	**LA-0.40-400-0%**	403	0.988
NA-0.45-350-0%	363	0.985	**LA-0.45-350-0%**	364	0.986
NA-0.45-400-0%	345	0.982	**LA-0.45-400-0%**	358	0.983
NA-0.35-350-7%	884	0.996	**LA-0.35-350-7%**	884	0.996
NA-0.35-400-7%	845	0.996	**LA-0.35-400-7%**	845	0.996
NA-0.40-350-7%	681	0.995	**LA-0.40-350-7%**	661	0.995
NA-0.40-400-7%	648	0.995	**LA-0.40-400-7%**	598	0.995
NA-0.45-350-7%	616	0.993	**LA-0.45-350-7%**	619	0.994
NA-0.45-400-7%	583	0.992	**LA-0.45-400-7%**	593	0.992
NA-0.35-350-10%	985	0.998	**LA-0.35-350-10%**	950	0.998
NA-0.35-400-10%	950	0.998	**LA-0.35-400-10%**	967	0.998
NA-0.40-350-10%	804	0.996	**LA-0.40-350-10%**	822	0.996
NA-0.40-400-10%	768	0.995	**LA-0.40-400-10%**	782	0.995
NA-0.45-350-10%	691	0.995	**LA-0.45-350-10%**	677	0.995
NA-0.45-400-10%	657	0.994	**LA-0.45-400-10%**	643	0.994

Table 2 shows that the calculated models for chloride ion ingress profile for each experimental data set of concrete mixes has high R^2, therefore the descending exponential function can show good predictions based on the obtained test data. Figure 2 shows a typical result.

In order to decide which performance-based parameter was the best for f(z) modeling further analyses were conducted among electrical resistivity (ER), sorptivity (S), compressive strength (CS) and calculated exponents for each concrete mix. The results of analysis were needed to select z from the above 3 parameters.

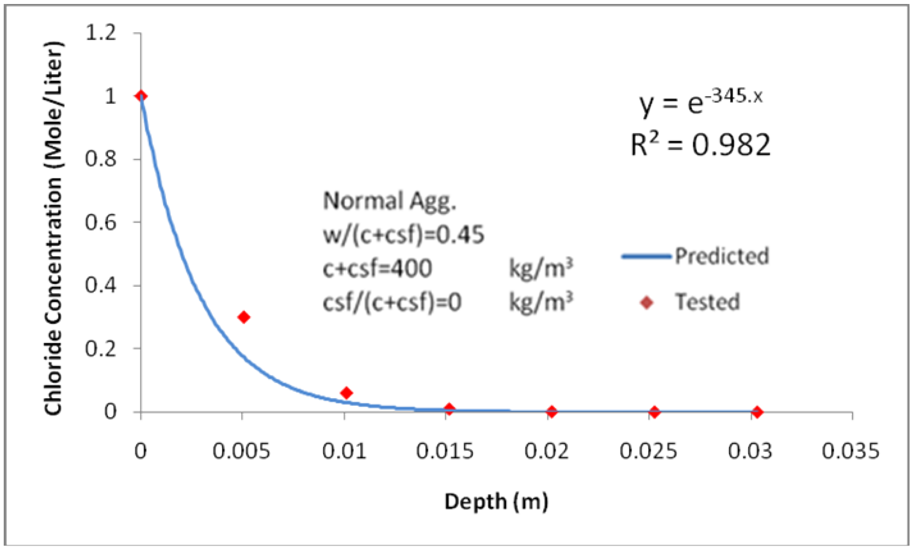

Figure 2. *Predicted and test results of chloride ion ingress profile for a typical concrete mix*

3.1 Correlation analyses of performance-based parameters with the chloride profile exponent (CPE)

In this section for any two type aggregates correlation analyses are applied and scatter plots are drawn to find the best parameter for modeling f(z). Table 3 shows the results of correlation analyses of performance-based parameters and chloride profile exponent for natural aggregate (NA) and semi-lightweight aggregate (LA) concretes. Figures 3-5 show the results for natural aggregate concrete and Figures 6-8 show the results for semi-lightweight aggregate concrete.

Table 3. *Correlation analysis results of performance-based parameters and chloride profile exponent for natural and semi-lightweight aggregate concretes*

Performance-Based Parameter	**Chloride Profile Exponent**	
	Natural Aggregate (NA)	*Semi-Lightweight Aggregate (LA)*
Compressive Strength (N/mm^2)	0.4659739	0.8546953
Electrical Resistivity (kΩ-cm)	0.9070410	0.9263005
Sorptivity (mm)/$t^{0.5}$	-0.720470	-0.4985385

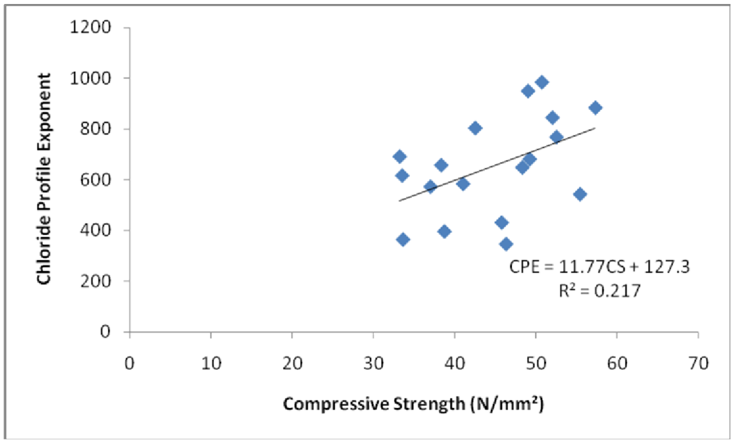

Figure 3. *Scatter plot for compressive strength and chloride profile exponent for natural aggregate concrete*

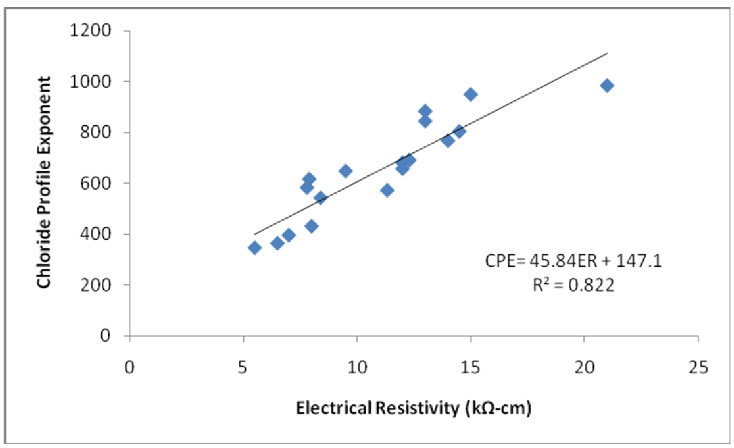

Figure 4. *Scatter plot for electrical resistivity and chloride profile exponent for natural aggregate concrete*

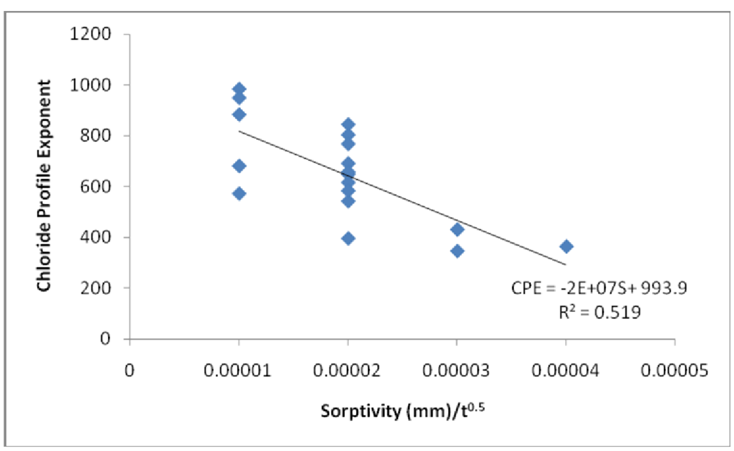

Figure 5. *Scatter plot for sorptivity and chloride profile exponent for natural aggregate concrete*

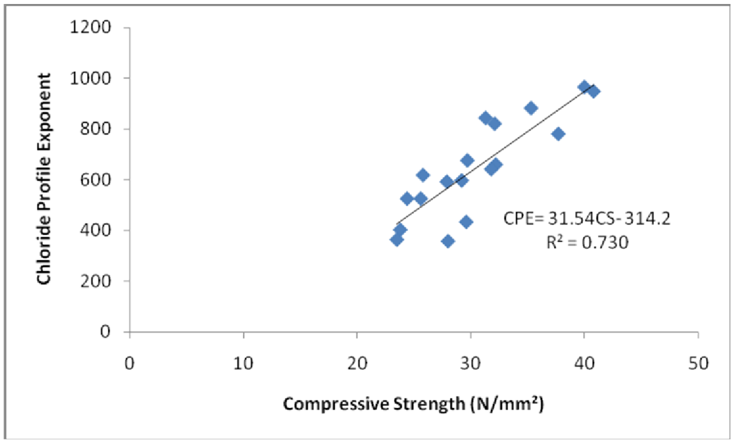

Figure 6. *Scatter plot for compressive strength and chloride profile exponent for semi-lightweight aggregate concrete*

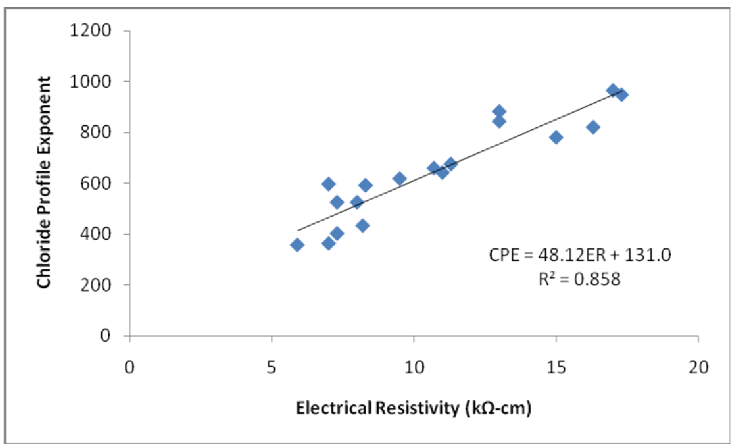

Figure 7. *Scatter plot for electrical resistivity and chloride profile exponent for semi-lightweight aggregate concrete*

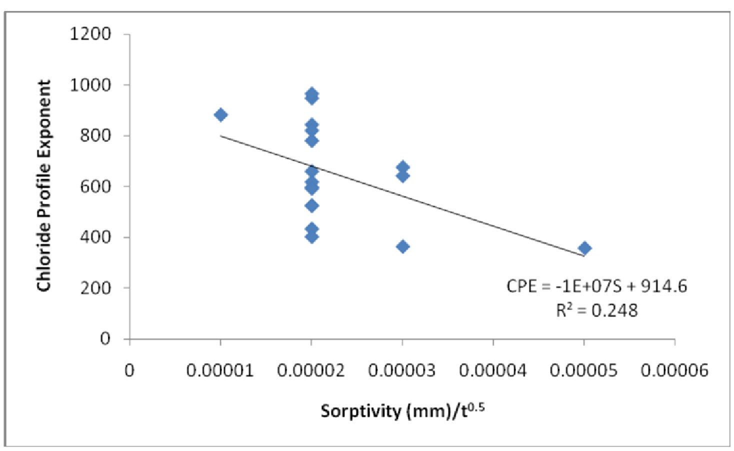

Figure 8. *Scatter plot for sorptivity and chloride profile exponent for semi-lightweight aggregate concrete*

Comparing the correlation factors in Table 3 shows that although there are some correlations between all 3 performance-based parameters with chloride profile exponent in the proposed model function but the highest values for both types of aggregates, i.e. NA and LA, belong to electrical resistivity. Therefore it is decided to finalize modeling with this parameter. Figure 9 depicts the electrical resistivity values for different 36 concrete mixes. It is obvious from the figure that by increasing the binder content electrical resistivity decreases in constant water-to-cementitious materials ratio. Another finding is that in a constant binder content increasing water-to-cementitious materals ratio leads to decreasing of electrical resistivity. Finally using condensed silica fume increases the electrical resistivity and higher in more substitution to cement content.

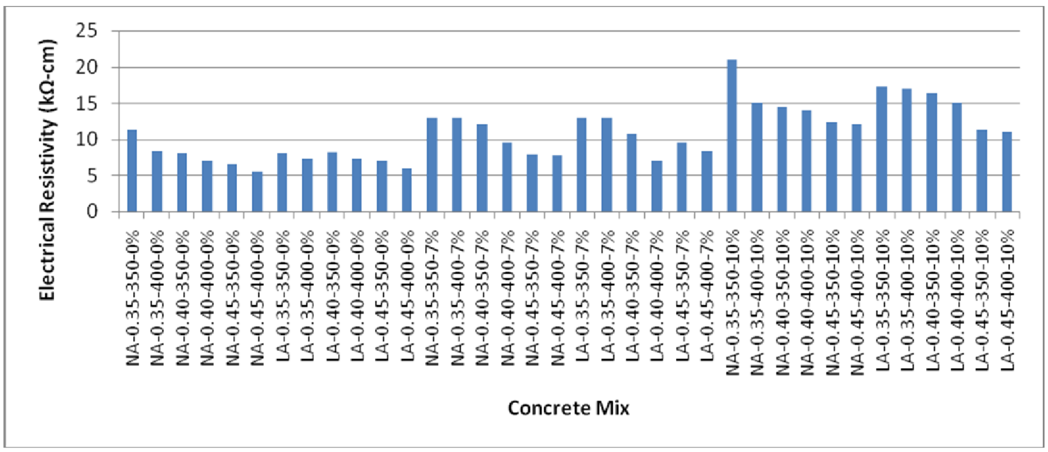

Figure 9. *Electrical resistivity values for different 36 concrete mixes*

4. Proposed chloride ion ingress models

Based on the above investigations and keeping in mind that the most easiest test method is of electrical resistivity (by Wenner array electrical resistivity device) among the concrete performanced-based parameters, this parameter is selected for further modeling of the chloride ion ingress profile. The proposed chloride ion ingress profile models for natural and semi-lightweight aggregate concretes in the form of Eq. (1) are as follows separately:

$$C(x) = e^{-(45.8ER + 147.1)x} \quad \text{; for natural aggregate concrete} \qquad (3)$$

$$C(x) = e^{-(48.12ER + 131)x} \quad \text{; for semi-lightweight aggregate concrete} \qquad (4)$$

where,

ER = concrete electrical resistivity (kΩ-cm)

It should be notified these models are only for accelerated chloride ion ingress in concrete at 28 days.

Applying these models to concrete mixes makes designer to be able to predict and compare the performance of concrete in corrosive environments. Service life can be studied in accelerated conditions by the models. It is possible to study the initial rate of chloride ion ingress by deravatives of the models. The initial rate is calculated at concrete surface, i.e. x = 0, and thus related only to the concrete electrical resistivity. Models for initial rate of chloride ion ingress in concrete are:

$$C' = -(45.8ER + 147.1) \quad \text{; for natural aggregate concrete} \quad (5)$$

$$C' = -(48.12ER + 131) \quad \text{; for semi-lightweight aggregate concrete} \quad (6)$$

From Eq.s (3) to (6) it is concluded that the more concrete electrical resistivity the less chloride ion ingress depth and initial rate. Since initial rate of chloride ion ingress in concrete is independent to x it is a suitable parameter to apply for different concrete mixes in service life prediction and comparison.

5. Conclusions

The penetration of chloride ion into concrete has been modeled by concrete electrical resistivity. The main scope of this paper is to develop a versatile tool for service life prediction and comparison when reinforced concrete structure design and/or maintenance and repair decision making are of main concerns. The results are summarized as follows:

Proposed test method of accelerated chloride ion ingress in concrete and models can be considered as rapid and simple tools of assessing the rate of penetration. They can be good evaluation methods for early stages of design and mix proportion selections considering corrosion as the main deterioration problem.

Chloride ion profile in concrete is able to demonstrate much characteristic information about a particular concrete which includes all mechanisms of chloride ingress and mainly the mix performance in corrosive environments.

The present test results indicate that the addition of condensed silica fume into concrete reduces the chloride ion ingress in concrete drastically. Also it is same for higher cementitious materials content in concrete.

The best performance-based parameter in modeling chloride ion ingress in concrete is concrete electrical resistivity. Thus modeling is done by this parameter.

The more is concrete electrical resistivity the less are chloride ion ingress depth and initial rate in concrete. Initial rate of chloride ion ingress in concrete is a suitable parameter to apply for different concrete mixes in service life prediction and comparison.

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Repairing Methods and Environmental Influence Regarding Concrete Piers

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Abstract

Piers are exposed to severe environmental conditions, and they require regular maintenance to prolong their service life. The Kyoto Protocol went into effect in Feb.2005, so the environmental influence also has to be taken into account when deciding the repair method. This paper discusses the relationship between repair methods and environmental influence. Two kinds of upper-pier members are selected: reinforced concrete deck and prestressed concrete deck. Repair methods considered are surface coating, cathodic protection and restoration to former cross-section. The service life of structures is set at 100 years. Calculation stages consist of material production, construction work and maintenance work. The environmental influence was evaluated on the basis of both LCCO2 (total generation of carbon dioxide during life span) and LIME(name of program soft for calculating quantity of whole environmental influence). Calculation results show the following things: ①of the three stages of a structure's life span, material production occupies approximately 40 ~ 70 % of LCCO2, ②restoration to former cross-section is larger LCCO2 , ③LCCO2 is intimately related to calculation result of LIME which is able to calculate such environmental factors as CO2, SOx, NOx and particles of soot.

Keywords: RC piers, maintenance methods, carbon dioxide, chloride induced deterioration

1. Introduction

Social infrastructures have played an important role in industrial and civil activities. Various kinds of facilities have been constructed and have performed practical functions. Structures are mainly constructed of concrete and steel, and are exposed to severe environmental conditions. Public facilities are required to maintain functionality during their service life, and they generally require regular maintenance.

The 21st Century is called the Environmental Century. Human activities have increased, especially since the Industrial Revolution, and have surpassed the ability of coping by natural means. Thus, Kyoto Protocol was proposed and was finally ratified in 2005. This protocol focused on discharge amounts of environmental heating gas, and discussions were continued at COP13, held in 2008. It is well known that social infrastructures have some environmental influence during production of materials, construction, service and demolition.

This paper focuses on reinforced concrete piers that are exposed to severe maritime conditions, and generally require regular maintenance during their service life. Various maintenance methods have been developed. Three methods are inspected and the amount of carbon dioxide discharge is calculated. Then, the relationships between maintenance methods and carbon dioxide discharges are discussed.

2. Methods for Calculating Environmental Influence

Calculation of environmental influence was based on LCCO2 and LIME. LCCO2 means the total generation of carbon dioxide during the item's life span. LIME is calculation software developed in Japan to determinate quality of overall environmental influence. In this paper, LIME includes such environmental factors as CO2, SOx, NOx and soot particles. Calculation stages consist of material production, construction and maintenance. Maintenance comprises repair and reconstruction required by deterioration of structures due to salt attack. The life span is considered to be 100 years in this paper. The equation of LCCO2 is given by Eq.(1). LIME is expressed as a non-dimensional number.

$$LCCO_2 = CO_{2i} + CO_{2rep} \times m \qquad (1)$$

Where CO_{2i} : generation of carbon dioxide in initial stage including production of materials and construction work

CO_{2rep} : generation of carbon dioxide during repair work

m : numbers of repairs during life span

3. Structures

The structures studied are piers, including upper decks and lower steel piles, as shown in Fig.1. The upper decks are composed of concrete beams and concrete slabs. The pier details are shown in Tab.1.

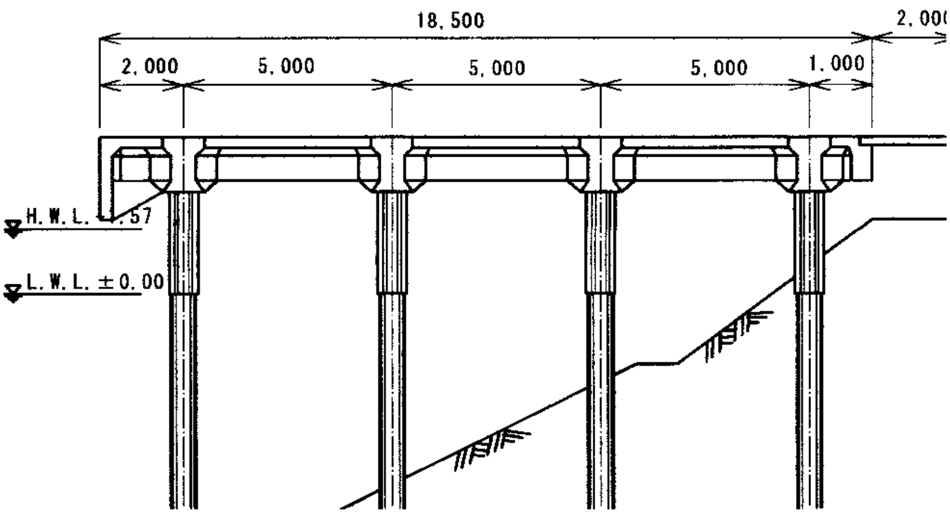

Fig.1 Type of Pier

Tab.1 Pier details

Name of port	A Port	H Port
Area of upper deck(m^2)	6,125	2,948
Type of upper deck member	RC beam and RC slab	RC beam and precast PC member
Year of construction	1992	2002

4. Calculation Process

(1) Calculation flow during life span

Fig.2 indicates the calculation stages during a life span of 100 years for RC members (A Port). The stages consist of material production, construction of structures and maintenance.

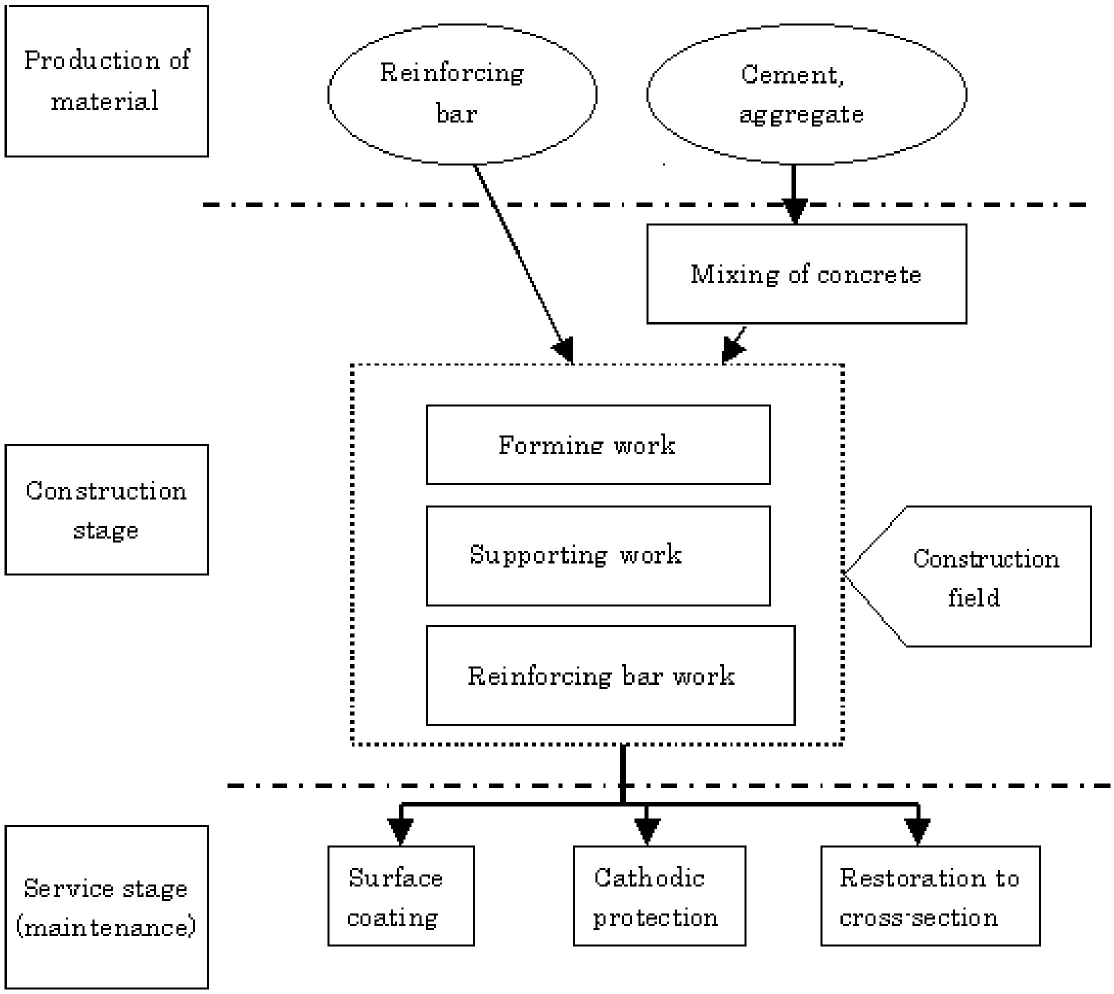

Fig.2 Calculation Flow during Life Span

(2) Generation of carbon dioxide during material production and construction

Generation of carbon dioxide is calculated for the material production and maintenance stages. Calculation results for Port A are summarized in Tab.2. Unit generation of CO2 is referenced from ref.2 and ref.3.

(3) Repair methods

When structures deteriorate to a certain stage, repair work has to be carried out. Repair methods considered are surface coating, cathodic protection and restoration to the former cross-section. The repair interval for the surfaces coating and cathodic protection methods is set in this paper, as shown in Tab.3.

Tab.2 Calculation Results for Generation of CO_2 (Port A)

Stage	Kind		Amount		Generation of CO_2		
			unit	amount	unit generation (kg- CO_2)	generation of CO_2 (t- CO_2)	total (t- CO_2)
Material production	Concrete ($6,332m^3$)	cement	m^3	1,830	766.6	1,403	1,999
		fine aggregate	t	5,078	3.7	19	
		coarse aggregate	t	6,668	2.9	19	
	Reinforcing bar		t	727	767.4	558	
Construction	Concrete mixing		t	14,583	7.68	112	466
	Support work	crawler crane etc.	ℓ	121,900	2.82	344	
	Formwork						
	Reinforcing bar work						
	Concrete placing	concrete pump etc.	ℓ	3,799	2.82	11	

Tab.3 Interval for Repair Methods

	Surface coating		Cathodic protection			Restoration to former cross-section
	Initial stage	Re-coating stage	Placing stage	Renewal of system	Renewal of electrodes	
Interval of repairing(yr)	——	15	——	25	50	——
Generation of carbon dioxide (kg/m^2)	13	14	69	4	65	286

For restoration to the former cross-section, the repair time is determined from the following probability concept1). Structures deteriorate due to salt ingress from the concrete surface. Reinforcing bars corrode at a certain chloride ion concentration in the concrete. Corrosion initiation time is calculated on the assumption that factors such as chloride ion diffusion, concrete cover, corrosion rate and so forth are random variables. Restoration to the former cross-section is carried out when the probability of corrosion reaches 10 percent. At this stage, 10 percent of the overall area of the upper deck of piers has to be repaired. The reconstruction time is decided when the cross-section of the reinforcing bars has decreased to 90 percent of their initial cross-section. The life span considered is 100 years. Calculation results are as follows.

Port A : Number of repairs 16, Years since reconstruction 93 years

Port H: Number of repairs 14, Years since reconstruction over 100 years

(4) Analysis of inventory

The amounts of materials for the repair methods are summarized in Tab.4. The amount of carbon oxide generation is calculated from ref.2 and re.3. Tab.2 indicates calculation results per unit area (m2) for each repair method.

5. Repair Methods and Environmental Impact

Fig.3 indicates the calculation results of LCCO2 and Tab.5 shows the ratio of CO2 in the material production, construction and maintenance stages.

Generally, the material production stage occupies approximately 40 ~ 70 % of LCCO2, although it depends on the repair method. For Port A, the repair stage of restoration to the former cross-section has a larger ratio of CO2, as is reasoned that severe deterioration requires disposal and reconstruction. Generally, construction work discharges a smaller amount of CO2.

As shown in Fig.3, restoration to the former cross-section indicates the largest LCCO2 of the three repair methods. It may be assumed that machine work for disposal of cover concrete and the use of cementatious materials to recover the disposal area generates a larger amount of carbon dioxide.

Fig.4 shows the relationship between the result of LCCO2 calculation and of LIME calculation. LIME includes such environmental factors as CO2, SOx, NOx and soot particles. However, it is likely that the relation of the two methods is intimate and can be expressed by almost a straight line.

Tab.4 Amount of Materials for Repair Methods

(1) Surface coating method

Initial stage	Machine	power generator	0.175	gasoline
	Material	epoxy resin	2.13 kg	
Re-coating stage	Machine	power generator	0.649	gasoline
	Materials	epoxy resin	2.13 kg	
		silica sand	12.6 kg	for pre-treating

(2) Cathodic protection method

Placing stage	Machine	power generator, compressor	15.4	gasoline
		grouting pump		
	Materials	cement, resin, anode material	3.15,0.50,0.41 kg	
		conduct bar, electric wire	0.04, 0.02 kg	
		electric tube	1.16 kg	
		box(polyvinyl chloride resin)	0.78 kg	
		wooden form	2.0 kg	
Renewal of system	Material	electric wire	0.02 kg	
		electric tube	1.16 kg	
		box(polyvinyl chloride resin)	0.78 kg	
Renewal of electrodes	Machine	power generator, compressor	15.4	gasoline
		grouting pump		
	Materials	cement, resin, anode material	3.15,0.50,0.41 kg	
		conduct bar	0.04 kg	
		wooden molding form	2.0 kg	

(3) Restoration to former cross-section

Working stage	Machine	power generator, compressor	depends on cover depth	light oil
		grouting pump		
	Materials	cement	depends on cover depth	
		silica sand	25.2 kg	
	Electricity		105 kWh	

Tab.5 Ratio of CO_2 Generation for Each Stage

Name	Repair method	Material	Const.	Repairing	Total
Port A	Surface coating	65	15	19	100
	Cathodic protection	56	13	31	100
	Restoration of cross-section	26	6	68	100
Port H	Surface coating	73	7	21	100
	Cathodic protection	62	6	32	100
	Restoration of cross-section	42	4	55	100

(%)

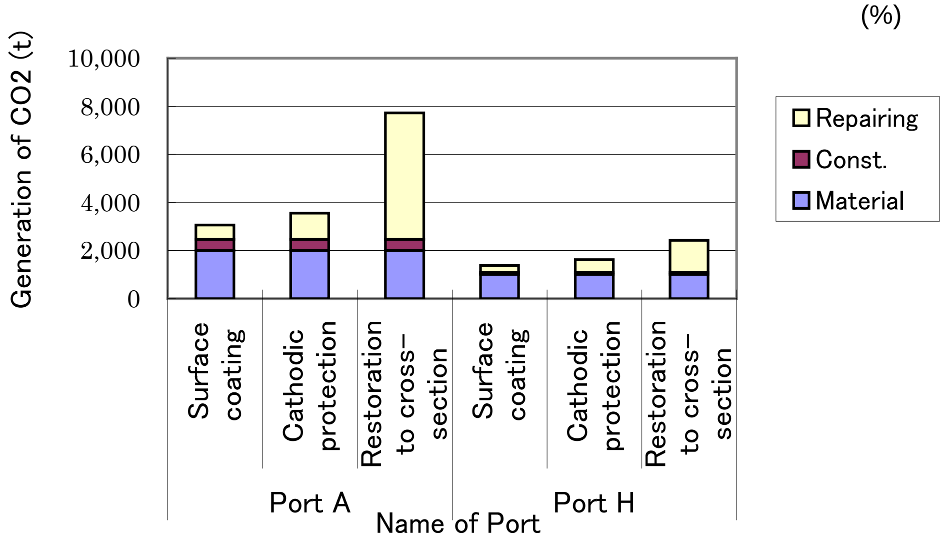

Fig.3 Results of $LCCO_2$ Calculation

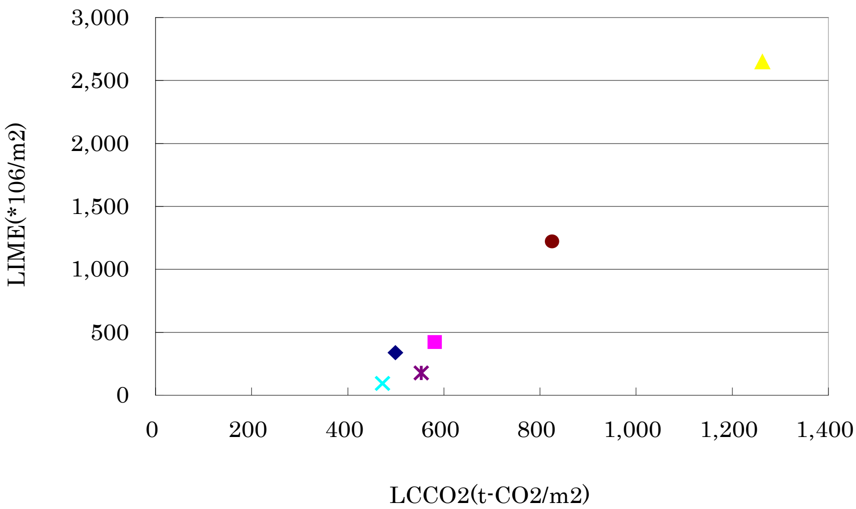

Fig.4 Comparison of $LCCO_2$ and LIME

6. Summary

In this paper, we have tried to estimate the environmental impact of concrete structures by LCCO2 and calculation by the software LIME. Calculation is carried out for the upper decks of piers for a life span of 100 years. The stages considered material production, structure construction and maintenance. For maintenance, three repairing methods were considered: surfaces coating, cathodic protection and restoration to former cross-section.

Calculations indicate the following:

(1)Of the three stages of a structure's life span, material production occupies approximately 40 ~ 70 % of LCCO2. Construction work discharges a smaller amount of CO2.

(2)Restoration to former cross-section requires the largest LCCO2 of the three repair methods.

(3)LCCO2 probably has an intimate relation with LIME which is able to calculate such environmental factors as CO2, SOx, NOx and soot particles.

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Reliability estimation of RC and composite structures

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Abstract

Methods of probability design and statistical control of reinforced concrete and composite structures lead to material economy and increase in reliability of buildings and constructions. Limit states of construction are to be caused by loads and material characteristics as well as by unfavourable environmental conditions. Methods of assessment of load-bearing capacity of single concrete and composite structural elements, and reliability of statically determined and undetermined systems are discussed. The reliability analysis of structural elements is based on dispersion of material strength properties and geometrical characteristics of elements.

Keywords: probability design, reliability, reinforced concrete, composite column

1. Introduction

Simple practical methods of probability design and statistical control of reinforced concrete (RC) and composite structures lead to material economy and increase in reliability of buildings and constructions. Limit states of construction are to be caused by loads, material and geometrical characteristics of elements as well as by unfavourable environmental conditions. In durability calculations the lifetime of structures before attaining the limit state is referred to a technical resource and economical category.

Reinforced concrete is heterogeneous material cast-in-site under variable conditions and reinforced with environmentally sensitive material. It is inevitable that there is a fluctuation in strength characteristics of constituent materials. This aspect is always taken into consideration in construction codes through the concept of characteristic strength and other properties such as diffusivity and permeability. As far as durability of structure is concerned, fluctuation related to stress state in a material is additional to fluctuation related to the material characteristics. Therefore when long exploitation life is required, it appears logical that probabilistic aspect is included in the prediction of the lifetime of structures. In general case, the reliability degree of a structure is to be ensured by their load carrying capacity and serviceability.

The purpose of this study is to present simple methods of assessment of load bearing capacity of single concrete and composite structural elements and reliability of statically determined and undetermined framed systems. The reliability analysis of structural elements is based on dispersion of material strength properties and geometrical characteristics of elements.

2. Methods of reliability assessment

Calculation model of simple structures (beams, columns, etc.) can be represented by system consisting of few conditioned elements characterising the probability of the load carrying efficiency in different zones of the structure. In the case of complicated and composite structures (trusses, frames, towers etc.) calculation model consist of many conditioned elements.

Reliability analysis of statically determined systems can be easily performed on the basis of distribution of material characteristics and relationships between parameters of structure. The complexity of analysis of statically undetermined systems is caused by correct estimation of internal forces and their redistribution. Therefore, in this case the reliability analysis gives only approximate quality assessment of the structure [1]. In the assessment of safety, suitability and durability of structures models consisting of conditioned elements, connection of which in the sense of reliability can be in series, parallel and mixed, are used [2]. Moreover, all stochastically dependent elements have to be combined into subsystems. Every separate system can form conditioned elements that present probabilistic characteristics of dangerous zones of the structure and are caused by the same load effects and material characteristics.

A simplified calculation model of hinged frame for the reliability analysis is shown in Fig. 1. The frame consists of RC beam, composite columns and foundations. It is symmetric because symmetric action of loads. Dangerous zones of the structure are shown by conditioned elements 1 – 8.

The failure of system consisting of *m* individual stochastically independent conditioned elements connected in chain will occur when at least one element fails. The faultless maintenance of the system with elements connected in series can be determined as product of all individual reliability probabilities $P_{1,suc}$, $P_{2,suc}$, …, $P_{m,suc}$. The reliability of the system is:

$$P_{suc} = \prod_{k=1}^{m} P_{k,suc} \, . \quad (1)$$

When the reliability of all elements is equal to P_0, the reliability of the system can be determined in the following way:

$$P_{suc} = P_0^m \,. \tag{2}$$

Obviously, the reliability of system consisting of elements connected in the chain can be lower that of a single member.

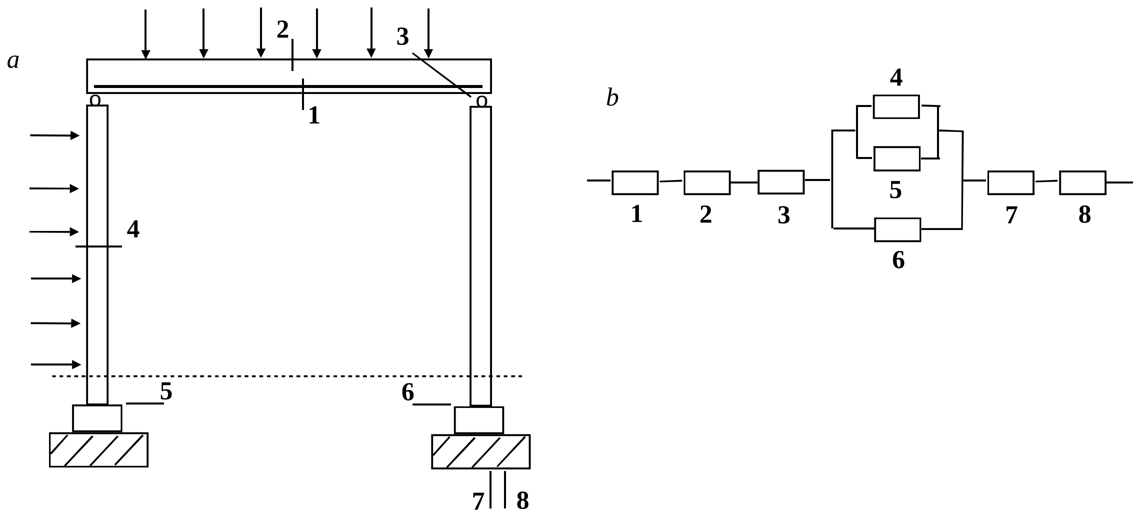

Figure 1. *Hinged RC frame (a) and flow-chart of calculation system with elements in series and parallel connection.*

The system with parallel connection of conditioned elements has to be used in the analysis of fault probabilities. In supporting an externally applied load, the failed members of a given parallel structure support no load, while all surviving members will share the applied load according to a specific manner. In the case of system consisting of *n* individual stochastically independent conditioned elements with failure probabilities $P_{1,fail}$, $P_{2,fail}$, …, $P_{n,fail}$ the probability of system failure can be determined as

$$P_{fail} = \prod_{k=1}^{n} P_{k,fail} \,. \tag{3}$$

Hereof the system reliability with elements in parallel is

$$P_{suc} = 1 - \prod_{k=1}^{n} (1 - P_{k,suc}) \,. \tag{4}$$

When the reliability of all elements is equal to P_0, the reliability of the system can be determined in a simple way:

$$P_{suc} = 1 - (1 - P_0)^n \,. \tag{5}$$

A parallel connection of elements provides the system reliability factors to be considerably increased. By using this model for statically undetermined structures the reliability of such structures appears to be higher than that of statically determinate ones.

By using estimates of reliability and durability of system elements the reliability of a stochastic system can be assessed. In the next paragraph the reliability of single elements is analysed.

3. Reliability of single elements

3.1. Reinforced concrete beam

In general case, the load carrying capacity of RC beam depends on dispersion of strength characteristics of materials, geometry and actions as well as maintenance and environmental effects. The loss of reliability can occur, mainly, in the case when high load effects coincide with low resistance of the element. By using characteristic concrete strength f_{ck} the moment resistance of a simple beam can be expressed as [3]

$$M_{Rk} = \mu b d^2 f_{ck}\,, \tag{6}$$

where μ is relative bending moment, b and d are width and effective dept of a beam, respectively. After determination of reinforcement cross-section area A_s and using characteristic strength of reinforcement f_{sk}, the moment resistance of the beam can be expressed in the following way:

$$M_{Rk} = \left[\frac{A_s f_{ck}}{d}\left(1 - \frac{A_s f_{yk}}{2 b f_{ck} d}\right)\right] b d^2 f_{ck} = d f_{yk} A_s - \left(\frac{(f_{yk})^2 A_s^2}{b f_{ck}}\right). \tag{7}$$

Eq. (8) can be written in the functional form:

$$M_{Rk} = \varphi(\, b, d, f_{ck}, f_{yk}) \tag{8}$$

and by using designation x_i for arguments in (9), it can be expressed in the following way:

$$M_{Rk} = \varphi(x_i)\,. \tag{9}$$

The variation of actual load-bearing capacity of the beam can be determined depending on the variation of factors x_i. Standard deviation of the actual moment resistance M_{act} caused by factors x_i is determined as

$$s_i^{M_{act}} = \left|\frac{\partial \varphi}{\partial x_i}\right| s_i\,, \tag{10}$$

where s_i is standard deviation of factor x_i. The mean quadratic deviation of moment resistance M_{act} taking into account the dispersion of all factors x_i is

$$s_{M_{act}} = \sqrt{\sum_i \left(s_i^{M_{act}}\right)^2}\,. \tag{11}$$

Let us examine reinforced concrete beam of cross section 50x25 cm loaded by moment M_{Ek} = 250 kNm. The cross section of tension reinforcement is A_s = 20 cm^2 and effective depth d = 47 cm. In the numerical analysis it is assumed that fluctuation of strength and geometric characteristics is ±5%.

For unfavourable effects of parameters, which determine the moment resistance, the probability of beam failure can be expressed as

$$P_{fail} = \frac{1}{2} - \frac{1}{2}\Phi\left(\frac{M_{act} - M_{Ek}}{s_{M_{act}}}\right), \tag{12}$$

where Φ is probability integral.

On the basis of the beam moment resistance M_{Rk} = 310 kNm and taking into account the mean quadratic deviation of moment resistance 21,60 kNm the probability of beam failure is:

$$P_{fail} = \frac{1}{2} - \frac{1}{2}\Phi\left(\frac{310-250}{21.60}\right) = \frac{1}{2} - \frac{1}{2}\Phi(2.78) = 0{,}0028 \text{ i.e. } 0.28\%.$$

It is determined that in unfavourable case less than 3 beams of 1000 could fail.

3.2. Composite column

By using characteristic strength of steel tube, concrete and reinforcement the plastic resistance of composite column is expressed as sum of constituents' resistances [4]:

$$N_{pl.Rk} = A_a f_{yk} + A_c f_{ck} + A_s f_{sk}\ , \tag{13}$$

where f_{yk} is characteristic strength of construction steel; A_a, A_c, and A_s are cross section areas of construction steel, concrete and reinforcement, respectively. In expression (13) the confinement effect of steel tube is neglected.

The Eq. (14) can be written in the form

$$N_{pl.Rk} = \varphi(A_a, A_c, A_s, f_{yk}, f_{ck}, f_{sk})\ , \tag{14}$$

and after substitution of arguments with x_i the expression (14) can be written in compact functional form:

$$N_{act} = \varphi(x_i)\ . \tag{15}$$

The variation of actual load-bearing capacity N_{act} can be determined depending on the variation of factors x_i. Standard deviation of N_{act} caused by factors x_i is determined as

$$s_i^{N_{act}} = \left|\frac{\partial\varphi}{\partial x_i}\right| s_i\ , \tag{16}$$

where s_i is standard deviation of factor x_i.

The results of dispersion analysis of composite column load bearing capacity are summarized in Table 1. The column consists of steel tube with diameter D = 21.9 cm and thickness t = 0.63 cm, reinforcement consist of 6 bars, diameter d_s = 1.6 cm; the characteristic resistance of construction steel f_{yk} = 235 MPa, reinforcement – f_{sk} = 500 MPa, concrete – f_{ck} = 35 MPa.

Table 1. Results of dispersion analysis of composite column load bearing capacity

Dispersion, %	Standard deviation s_i^N, kN						Total deviation $s_{N_{act}}$ kN
	s_D^N	s_t^N	$s_{d_s}^N$	$s_{f_{yk}}^N$	$s_{f_{ck}}^N$	$s_{f_{sk}}^N$	
5	127	45	62	53	48	38	169
10	249	102	148	121	116	102	365

The probability that actual load bearing capacity N_{act} is less than design capacity N_{Rk} is determined with expression:

$$P_{fail} = \frac{1}{2} - \frac{1}{2}\Phi\left(\frac{N_{act} - N_{Rk}}{s_{N_{act}}}\right), \tag{17}$$

where $s_{N_{act}}$ is the mean quadratic deviation of actual column resistance.

4. Conclusions

In the reliability analysis of RC beam, when the fluctuation of strength and geometric characteristics is ±5%, in the unfavourable case the probability of beam failure is 0.28%. The estimation of composite column resistance shows that, when dispersion of all design factors is −5%, the probability of column failure is 0.065%, for dispersion −10% that could be 6.8%.

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ROTI – Expert analysis on the state of the nation of built infrastructure

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Abstract

This paper describes the process to bring together leading experts to formulate a report on the state of the nation on built infrastructure. The process results are marketed not only to specialists but also to decision-makers and the public at large. With its second execution the ROTI process has found its place as the definitive overall description of the current state and trends in the Finnish construction and real estate sectors.

Keywords: expert analysis, built infrastructure, remediation debt

1. Introduction

Built infrastructure forms about 70 per cent or 320 bn. Euros of Finland's national assets. This high portion is due to long distances, cold winters, traditionally investment-intensive industries, and recent large-scale migration from countryside to urban areas. From a household point of view, home ownership is exceptionally common and one's biggest investment is most typically a mortgage. Depreciation and payback periods play a remarkable role for the finances of the whole society.

In spite of their evident importance, statistics on both public and private sectors' built assets are either non-existent, non-comparable or based on limited bookkeeping standards. Due to this, The Finnish Association of Civil Engineers RIL imported and developed further an infrastructure analysis tool that is based on an orchestrated expert opinion. The process was named ROTI, an abbreviation for the State of the Nation on Built Infrastructure. The results are presented in the form of a school certificate and a qualitative report.

The analysis has now been executed twice and the results were reported in 2007 and 2009. This paper is based on the second execution.

2. Method

The generic method for gathering and analyzing data was imported from analogical projects by American Society of Civil Engineers ASCE (USA) and Institution of Civil Engineers ICE (GB). These methods were customized to Finnish conditions to create an objective reference point for all stakeholders among construction and real estate sectors.

As opposed to its international counterparts, ROTI involved all relevant national experts independent of their RIL membership status. Major reference to find panelists was the Forum for Construction and Real Estate, KIRA-Foorumi, an informal consortium of 11 associations.

A total of 75 experts were invited to participate in the ROTI process from August 2008 to February 2009. The experts were divided to five panels, three of which were based on actual physical structures: Buildings, Traffic Networks, and Utilities. In addition, two crosscutting panels were established for Energy Efficiency and Education and Development.

Each panel had 10-18 experts and 4-6 meetings. The process was steered by management group which consisted of project chairman, project coordinator and panel chairs.

The panelists started their work in a kickoff event, where the ROTI process was described and appropriate vocabulary agreed upon. The basic criteria for evaluative work were set to be the goals of the National Strategy on Construction Policy from year 2003. According to them, the products and services of the construction and real estate sector should be safe, not threaten one's health, and be functional, economical and ecological. The panelists were also reminded of Maslow's hierarchy of needs.

In their first meeting, each panel received a set of 50-150 slides of statistical data. The sets were prepared by a consultant based on the preliminary scope of the panel, and they were complemented according to the needs identified in the first meetings. The data was used as background for the expert discussions.

The panels were requested to report their opinion using four tools: a school grade describing the state of the nation, an arrow describing the direction for development in the short term, a simplified list of positive and negative signals from the field, and a qualitative text describing the current opportunities and threats in each field.

Final results were checked, overlapping topics rearranged and conclusions ratified by the management group.

3. Results

An overall grade of 8- was given to the state of nation on built infrastructure. The scale was from 4 to 10, the latter meaning the best in the world.

In addition, a total of 26 grades were given to the subcategories. The best individual grades, both 9½, were given for airports and the students studying the field in educational institutions at the moment. The worst grade, 5, was given for the funding of higher education. The widely varying titles of the subcategories illustrate the power of simplification. Although analyses were based on non-comparable case-by-case statistics, all results were represented in the same scale.

The report estimated that the so-called remediation debt is 35-55 bn. Euros. The term describes the investment that would be needed to bring infrastructure back to good condition, as opposed to its current wear and limited operability. Most of the remediation debt is in buildings. Repair and retrofitting investments should grow 1.5-fold from their present levels on buildings and traffic networks. For water and sewage networks they should grow 3-fold.

More than one million Finns live in apartment buildings that were made in the 1960s and 1970s. These buildings are now coming to the age of renewal, which should result in improved functionality, architecture and energy efficiency. Renewal should be applied not only to buildings but also on the regional level, including public infrastructure and transport.

To speed up the needed renovations, a system of routine inspections for buildings was proposed. They would provide invaluable and openly comparable data to the decision-making processes, especially to those of privately owned apartment buildings. At best, the certified results of such inspections would begin to affect the market prices directly.

Finally the report concluded that almost half of Finland's greenhouse gas emissions are generated in buildings or traffic. However, hastening and exaggerating the emission cuts in the building specifications can undermine the cumulated experience of constructing safe and sound infrastructure for local conditions.

The finalized report was presented to the Minister of Housing in early April 2009.

4. Conclusions

Expert analysis provided the justified arguments that were sought after, and report's core findings were widely presented in specialist media in the following months. The stakeholders considered that the project was successful and its results provided them right kind of tools, especially for sector brand management. Networking between individuals and otherwise separate projects was also highly appreciated.

Further development will be needed in renewing the concept to make it refreshingly attractive for both panelists and media in 2011. The total value of built infrastructure or its remediation debt is already common knowledge and even a part of the national government program for the period 2007-2011. Thus most of the goals of the original concept have been achieved and new goals need to be set for the next round.

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Estimating the service-life of concrete structures subjected to carbonation on the basis of the air permeability of the concrete cover

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Abstract

An effective lifetime management of buildings and civil infrastructures needs methods for verifying the compliance of their service-life with the design value and, in the case of non-compliance, for predicting the time-evolution of degradation, thus enabling the owner to plan adequate maintenance and repair actions. In the case of concrete structures service-life is mainly determined by the penetrability of the concrete cover.

The paper presents a probabilistic method for predicting service-life of concrete structures, whose most relevant degradation mechanism is carbonation, as is the case for example for concrete buildings. The method requires as input variables the air permeability and the thickness of the concrete cover. In a first approximation it assumes that carbonation progresses proportionally to the square root of time.

A key element of the method is the relationship existing between air permeability and the probability distribution function of the carbonation rate. This has been derived with likelihood inference applied to data collected on site on a concrete building by measuring air permeability with the Torrent permeability tester and carbonation depth on cores taken out from the structure.

Keywords: service-life prediction, concrete structures, carbonation, air permeability, Torrent permeability tester.

1. Introduction

For an effective lifetime management of buildings and civil infrastructures durability assessment methods are needed in order to verify the compliance of the expected service life with the design value and, in the case of non-conformity, for making reasonable predictions about the time-evolution of degradation. These predictions enable the owner to plan adequate maintenance and repair actions.

In the case of concrete structures, durability and service-life are mainly determined by the penetrability of the finished concrete cover layer, which is influenced not only by the concrete mix but also by the placing and curing conditions. The penetrability of the concrete cover can be characterized by in situ measurements of the air permeability according to the Torrent method [1]. In Switzerland the Torrent method is a standard test for the assessment of the in situ permeability [2].

This paper reports on the results of an investigation performed with the aim of setting up a durability assessment method and a service-life prediction procedure for concrete structures, whose most relevant degradation mechanism is due to carbonation. To this purpose, on site measurements of the air permeability and of the carbonation depth have been performed on more than 50 points distributed over the facades of a 35 years old concrete building located in the urban area of Lugano, in southern Switzerland.

The relationship existing between the carbonation rate and the air permeability has been explored and validated by means of statistical inference methods. These methods are presented in detail in the first part of the paper. Basing on the resulting relationship and on notions of reliability theory, a procedure for computing service life is then presented. As an application example, service life values are calculated for some typical air permeability distributions. It is also briefly discussed how the procedure can be applied to specify compliance criteria for the air permeability, when this quantity is used as a performance indicator within a performance-based durability assessment.

2. Exploring the relationship existing between carbonation rate and air permeability of the concrete cover

2.1 Model specification

The data points shown in figure 1 represent the carbonation rate determined for the investigated building as a function of the air permeability. A strong dispersion of the data is observed owing mainly to the different exposition conditions of the facades and to material heterogeneity (concrete compressive strength is in the range 25 – 80 MPa).

The data are denoted by the pairs $\{(kT_1,c_1), ..., (kT_n,c_n)\}$, where c_i is the carbonation rate and kT_i is the air permeability at the point i on the structure. The carbonation rate is defined by the empirical relation $X_C(t) = c\sqrt{t}$ [3] with X_C the carbonation depth, as measured by the phenolphthalein method, and t the age of the structure.

In the present analysis we regard the kT_i as fixed and the c_i as the realizations of random variables, whose dependence on the kT_i is to be explored. Since the carbonation rates are non-negative, it is unlikely that the normal distribution would provide a good model. As an alternative, models based on the Weibull distribution are considered. A random variable C is said to follow a Weibull distribution with parameters μ and α if its probability density function has the form

$$f(c) = \frac{\alpha}{\mu}\left(\frac{c}{\mu}\right)^{\alpha-1} \exp\left(-\left(\frac{c}{\mu}\right)^{\alpha}\right), \quad c > 0, \tag{1}$$

where the parameters μ and α are both positive. The expectation of a Weibull distributed variate is given by $E(C) = \mu \cdot \Gamma(1/\alpha + 1)$ with $\Gamma(\cdot)$ the gamma function.

Allowing for the possible effect of the covariate kT requires a model for its influence on the carbonation rate c. Basing on the fact that for laboratory concretes, under controlled conditions, a fairly good positive, linear correlation between the carbonation depth and the logarithm of the air permeability is generally observed and that for sufficiently low values of kT the carbonation reaction does not seem to take place [1,4], it is assumed that the relationship between the carbonation rate and the air permeability is described by the following function

$$E(C) = \begin{cases} \log_{10}\left(\frac{kT}{kT_0}\right)^{a} & \text{for } kT \geq kT_0 \\ 0 & \text{for } kT < kT_0 \end{cases} \tag{2}$$

The three model parameters a, $\log_{10}(kT_0)$ and α can then be estimated by the maximum likelihood method [5]. The likelihood for the model is easily evaluated from (1) and (2) as

$$L(a, \log_{10}(kT_0), \alpha) =$$

$$= \frac{\alpha^{n}\Gamma(1/\alpha+1)^{n\alpha}}{a^{n\alpha}} \frac{\left(\prod_{i=1}^{n} c_i\right)^{\alpha-1}}{\left(\prod_{i=1}^{n} a\log_{10}(kT_i/kT_0)\right)^{\alpha}} \exp\left\{-\sum_{i=1}^{n}\left(\frac{c_i\Gamma(1/\alpha+1)}{a\log_{10}(kT_i/kT_0)}\right)^{\alpha}\right\}, \tag{3}$$

where n is the total number of data pairs (kT_i, c_i). The maximum likelihood estimate is found by maximizing expression (3) or the log-likelihood $\ell = \log\left(L(a, \log_{10}(kT_0), \alpha)\right)$ with respect to the parameters a, $\log_{10}(kT_0)$ and α,

$$\left(\hat{a}, \log_{10}\left(\widehat{kT_0}\right), \hat{\alpha}\right) = \arg\max L(a, \log_{10}(kT_0), \alpha) = \arg\max \ell(a, \log_{10}(kT_0), \alpha). \tag{4}$$

Substituting the data shown in figure 1, numerical maximization of (3) leads to the maximum likelihood (ML) estimators

$$\hat{a} = 0.923, \ \log_{10}\left(\widehat{kT_0}\right) = -17.826 \ \text{ and } \ \hat{\alpha} = 1.924, \tag{5}$$

with a maximized log-likelihood of -71.82.

Approximate 95% confidence intervals for the model parameters have been obtained by analyzing the profile likelihood function (a detailed description of the method by which the confidence intervals have been determined is given in section 2.2). For the parameter a the analysis gives a confidence interval of [0.7, 1.1]. The fact that this interval includes 1 provides evidence that a = 1. For the sake of simplicity (reduction of the free model parameters number from 3 to 2), in the subsequent analysis the model given by expression (2) is simplified by setting a = 1.

Under this constrain, maximization of (3) leads now to the following ML-estimators

$$\log_{10}(\widehat{kT_0}) = -17.790 \quad \text{and} \quad \hat{\alpha} = 1.949, \qquad (6)$$

with a maximized log-likelihood of -72.14. The corresponding mean carbonation rate curve is shown relative to the data in figure 1. The fact that the maximum value of the log-likelihood changes only slightly provides further support for the plausibility of the simplification.

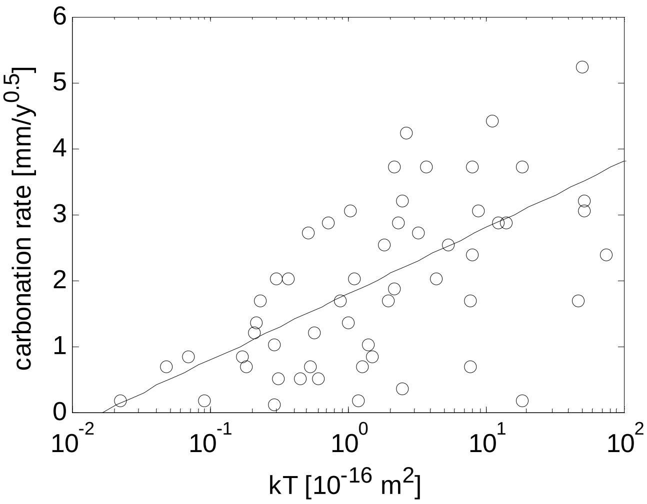

Figure 1. *Carbonation rate against the air permeability of the concrete cover. The solid curve represents the mean carbonation rate as a function of air permeability.*

The curve seems to give a reasonable match to the pattern in the observed data. From the estimator $\log_{10}(\widehat{kT_0})$ it is possible to calculate the estimator of $\widehat{kT_0}$, the air permeability threshold value for which the carbonation rate vanishes. The calculation gives $\widehat{kT_0}$ = 0.016·10^{-16} m^2.

2.2 Confidence intervals for the model parameters

The uncertainty of the maximum likelihood estimators of $\log_{10}(kT_0)$ and α has been determined by means of the likelihood-ratio-statistics $W = -2\tilde{\ell}_p(\theta)$, where $\tilde{\ell}_p(\theta) = \ell_p(\theta) - \ell(\hat{\theta}_{ML})$ is the log-relative-likelihood and θ stands for the model parameters [5]. The function $\ell_p(\theta)$ is the so-called profile log-likelihood and is defined as follows

$$\ell_p(\log_{10}(kT_0)) = \max_\alpha \ell(\log_{10}(kT_0), \alpha) \quad \text{and} \quad \ell_p(\alpha) = \max_{\log_{10}(kT_0)} \ell(\log_{10}(kT_0), \alpha) \qquad (7)$$

for $\log_{10}(kT)$ and α, respectively.

The function $\ell_p(\theta)$ represents the profile of the log-likelihood surface viewed from the θ axis. An approximate (1-δ) confidence interval for θ is then defined by the following set

$$\left\{\theta : \tilde{\ell}_p(\theta) \geq -\frac{1}{2}\chi^2_{1-\delta}(1) =: d\right\}, \quad (8)$$

where $\chi^2_{1-\delta}(1)$ is the (1-δ) quantile of the $\chi^2(1)$-distribution. In the case of a 95% confidence interval (δ = 5%), the value of the threshold d is -1.92. The limits of the interval are thus determined by solving numerically the equation $\tilde{\ell}_p(\theta) - d = 0$. The procedure is illustrated in figure 2, where the profile log-likelihood functions for the two model parameters in the neighborhood of their ML-estimators are shown.

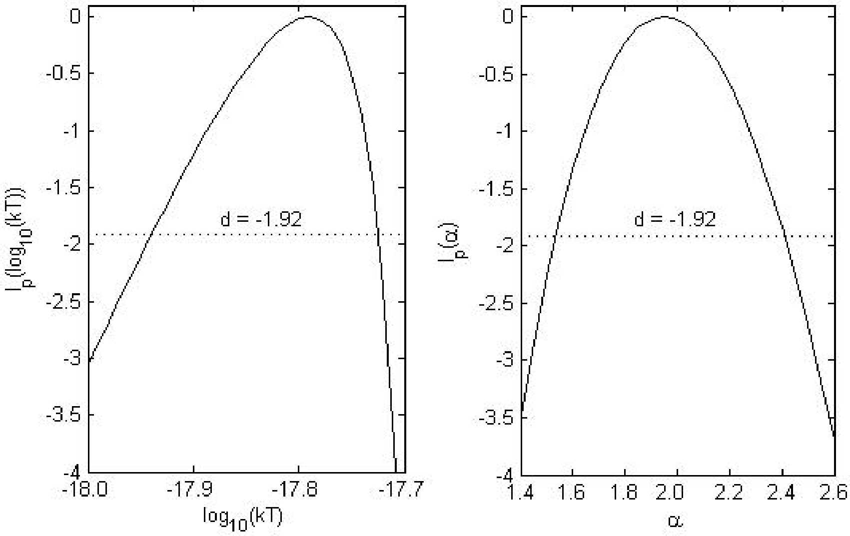

Figure 2. *Profile log-likelihood for the two model parameters in the neighborhood of their respective ML-estimators.*

The resulting confidence intervals are [-17.94, -17.72] for $\log_{10}(kT_0)$ and [1.53, 2.41] for α. From the first interval it is possible to derive a confidence interval also for the threshold kT_0. The calculation gives [$0.011 \cdot 10^{-16}$ m^2, $0.019 \cdot 10^{-16}$ m^2]. This result is in good agreement with experimental evidence presented in [1].

2.3 Model diagnostics

The results obtained so far can be sensitive to the accuracy of the fitted model. It is therefore necessary, in order to use them for further analysis, to check the validity of the assumed model. This is not so straightforward, because the carbonation rates c_i have non-identical distributions. However, if the fitted model c_i ~ Wb($\hat{\mu}_i, \hat{\alpha}$) with $\hat{\mu}_i = \log_{10}(kT_i/\widehat{kT_0})/\Gamma(1/\hat{\alpha}+1)$ is accurate, then the standardized variables

$$\tilde{c}_i = \left({}^{c_i}/_{\hat{\mu}_i}\right)^{\hat{\alpha}} \quad (9)$$

are such that $\tilde{c}_i \sim$ Exp(1). Hence, one can calculate the values of the standardized variables on the basis of the fitted model, and use probability and quantile plots to compare them against an exponential distribution with parameter 1. With the $\tilde{c}_i$ assumed to be in increasing order, a probability plot consists of the pairs

$$\left\{\left(i/(n+1),\ 1-e^{-\tilde{c}_i}\right);\ i=1,\ldots,n\right\}, \tag{10}$$

while a quantile plot comprises the pairs

$$\{(-\log(1-1/(n+1)), \tilde{c}_i);\ i=1,\ldots,n\}. \tag{11}$$

The probability and quantile plots for the carbonation rate are shown in figure 3. In both cases the points are sufficiently close to linearity to lend support to the fitted model.

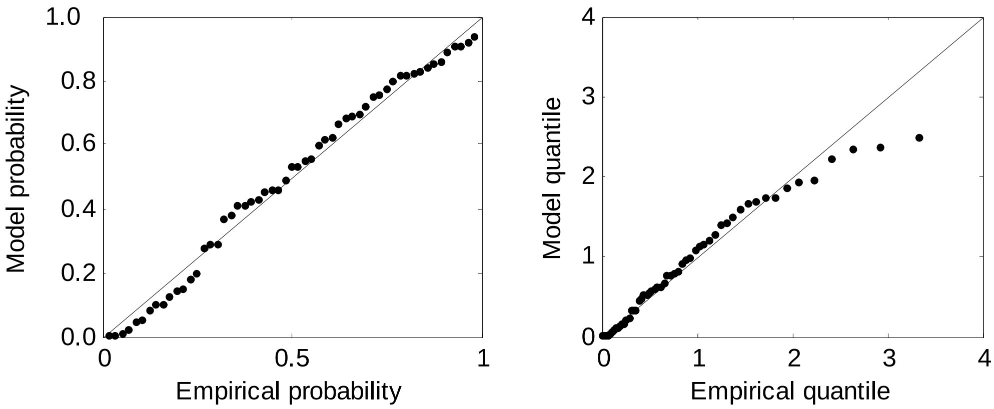

Figure 3. *Probability (left) and quantile plot for fitted model for the carbonation rate.*

2.4 Results of the analysis

The main results of the preceding analysis can be summarized as follows:

1) the relationship linking the mean carbonation rate with the air permeability of the investigated on-site concrete is

$$\bar{c} = \log_{10}\left(kT/\widehat{kT}_0\right) \tag{12}$$

for $kT \geq \widehat{kT}_0$ = 0.016·10^{-16} m^2 and is $\bar{c} = 0$ elsewhere;

2) the carbonation rate is statistically distributed according to a Weibull distribution with scale parameter $\hat{\mu}(kT) = \bar{c}(kT)/\Gamma(1/\hat{\alpha}+1)$ and shape parameter $\hat{\alpha}$ = 1.949.

Since the scale parameter $\hat{\mu}$ depends upon the air permeability, expression (1) can also be considered as the conditional density function $f_{c|kT}(c|kT)$ of the carbonation rate c given kT. Within the assumed model the function results to be

$$f_{c|kT}(c|kT) = \frac{\hat{\alpha}\left(\Gamma(1/\hat{\alpha}+1)\right)^{\hat{\alpha}}}{\bar{c}} \left(\frac{c}{\bar{c}}\right)^{\hat{\alpha}-1} \exp\left(-\left(\frac{c\Gamma(1/\hat{\alpha}+1)}{\bar{c}}\right)^{\hat{\alpha}}\right) \quad (13)$$

for $kT \geq \widehat{kT}_0$ and 0 elsewhere. The function is plotted in figure 4 for some values of kT.

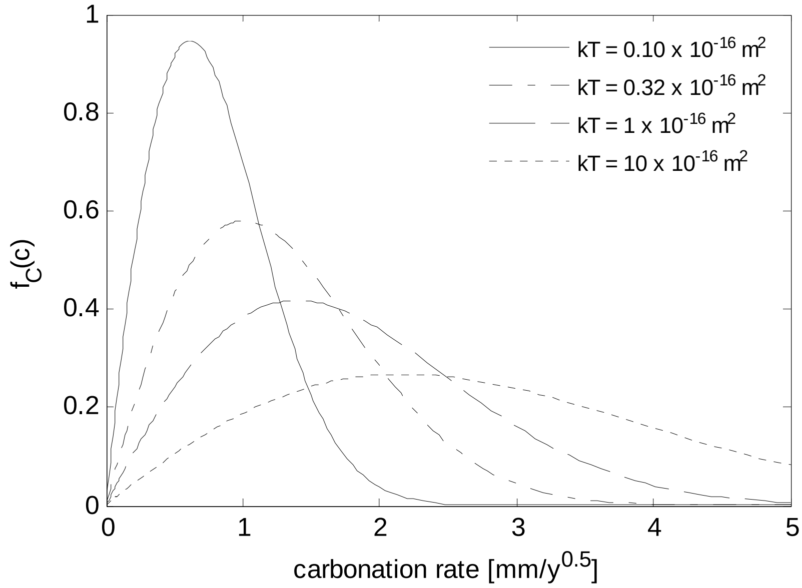

Figure 4. *Conditional density functions of the carbonation rate for* kT *= 0.10, 0.32, 1.0, and 10.0·10*$^{-16}$ *m*^{2}*.*

3. Probabilistic service life computation method

3.1 Probabilistic definition of service life

Service life is defined as the time period from start of the use of a structure or of part of it, during which the intended performance is achieved. With regard to durability and within a probabilistic approach, this period of time ends when the probability of reaching some limit state exceeds a predefined value.

According to reliability theory, if $S(t)$ represents the time dependent solicitation acting on the structure and $R(t)$ is the resistance that the structure opposes against it, then the event expressing failure can be specified as $\{\text{failure}\} = \{R(t) - S(t) < 0\}$. The failure probability P_f is so defined as

$$P_f(t) = P\{R(t) - S(t) < 0\} \quad (14)$$

and the service life t_{SL} as

$$t_{SL} = \sup\{t: P_f(t) \leq P_{f,max}\}. \quad (15)$$

The service life is dependent on the required reliability level $P_{f,max}$. Reliability requirements are generally expressed in terms of a statistical reliability index β according to the equation $P_{f,max} = \Phi(-\beta)$, where Φ is the cumulative distribution function of the standard normal distribution.

In the European standard EN 1990, a fixed minimum reliability index β = 1.5 (corresponding to a failure probability of 6.681%) is recommended for serviceability limit states and for a time period of 50 years. Some authors propose to graduate the reliability requirements according to the economic consequences deriving from a violation of the serviceability limit state. Rackwitz [6], for example, considers as a ranking parameter for the reliability index the ratio between the costs related to risk minimization and those related to the rehabilitation actions.

Gehlen [7] suggests that the reliability index has to be linked not only to the cost ratio introduced by Rackwitz but also to the environmental exposition classes according to EN 206. The reliability indexes suggested by Rackwitz and Gehlen are listed in table 1.

Costs ratio	Exposition classes	Reliability index β
Low	XC4, XD1, XS1, XS3, XD3	2.0
Normal	XC2, XC3, XS2, XD2	1.5
High	XC1	0.5

Table 1. *Required reliability index at the end of the service life as a function of the costs ratio and the environmental exposition classes according to Rackwitz and Gehlen [6,7].*

3.2 Computation of the failure probability for carbonation induced corrosion

If the solicitation S and the resistance R are independent random variables with probability density functions (pdf's) $f_S(s)$ and $f_R(r)$ (and cumulative distribution functions $F_S(s)$ and $F_R(r)$) respectively, then the probability of failure defined by equation (14) can be computed using the following convolution integral

$$P_f(t) = \int_{-\infty}^{+\infty} \int_{-\infty}^{s} f_R(r)\, f_S(s) ds dr = \int_{-\infty}^{+\infty} F_R(s;t)\, f_S(s;t) ds. \quad (16)$$

For carbonation induced corrosion, the solicitation, to which the structure is subjected, is represented by the time dependent carbonation depth $X_C(t)$ and the resistance is represented by the concrete cover thickness D_C. Here it is assumed that the serviceability limit state corresponds to the onset of reinforcement depassivation. In this case, equation (16) can be written as follows

$$P_f(t) = \int_{-\infty}^{+\infty} \int_{-\infty}^{x_c} f_{D_c}(d_c)\, f_{X_c}(x_c;t) dx_c d(d_c) = \int_{-\infty}^{+\infty} F_{D_c}(x_c)\, f_{X_c}(x_c;t) dx_c. \quad (17)$$

Knowledge of the probability distributions of the carbonation depth at time t and of the concrete cover thickness is thus fundamental for computing the failure probability. The distribution of the concrete cover can be derived from measurements performed non-destructively by means of commercially available covermeters. The distribution of the carbonation depth can be determined on cores by means of the phenolphthalein method.

This latter method has two main drawbacks: firstly a rather large number of cores is required to gather sufficient data for a reliable determination of the carbonation depth distribution and, secondly, the method is not applicable on newly constructed structures, for which the carbonation reaction has still not taken place. If an assessment of durability has to be performed without damaging the structure or immediately after the end of the construction phase, for example in order to ascertain whether the requirements of the owner concerning service life are satisfied or not, alternative ways have therefore to be devised.

In the following, basing on the results summarized in section 2.4, an indirect method for estimating the distribution of the carbonation depth at time t is presented.

3.3 Distribution function of the carbonation depth

Using properties of associated random variables and the empirical relation describing the progress of carbonation, $X_C(t) = c\sqrt{t}$, the pdf of the carbonation depth X_C at the time t can be written as

$$f_{X_c}(x_c, t) = \frac{1}{\sqrt{t}} f_C\left(\frac{x_c}{\sqrt{t}}\right), \qquad (18)$$

where $f_C(c)$ is the pdf of the carbonation rate. Since the conditional density function of the carbonation rate given the air permeability kT is known (see equation (13)), $f_C(c)$ can be computed as follows

$$f_C(c) = \int_{kT_0}^{+\infty} f_{c|kT}(c, kT)\, f_{kT}(kT) d(kT), \qquad (19)$$

where $f_{kT}(kT)$ is the pdf of the air permeability.

It is shown by some authors [8] that the air permeability follows a lognormal statistical distribution. This is equivalent to say that the logarithm of kT is normally distributed, $\log_{10}(kT) \sim \mathrm{N}\left(\mu_{\log_{10}(kT)}, \sigma^2_{\log_{10}(kT)}\right)$. Substitution of the appropriate functions for $f_{c|kT}$ and f_{kT} into equation (19), followed by (numerical) integration, gives the pdf of the carbonation rate and, hence, by virtue of equation (18), the pdf of the carbonation depth. Under the assumption that the results of section 2.4 are generally valid, measurements of the concrete air permeability thus allow to determine, for a given age t of the structure, the pdf of the carbonation depth.

Examples of the cumulative distribution function $F_{X_c}(x_c, t)$ of the carbonation depth are shown in figure 5 for t = 1 year, $\sigma_{\log_{10}(kT)}$ = 0.4 and $\mu_{\log_{10}(kT)}$ = -16.2, -16.0 and -15.0 (for t = 1 year the cumulative distribution function of the carbonation depth coincides with that of the carbonation rate). The values of $\mu_{\log_{10}(kT)}$ correspond to a geometric mean of the air permeability of 0.63, 1.0 and 10.0·10^{-16} m^2, respectively.

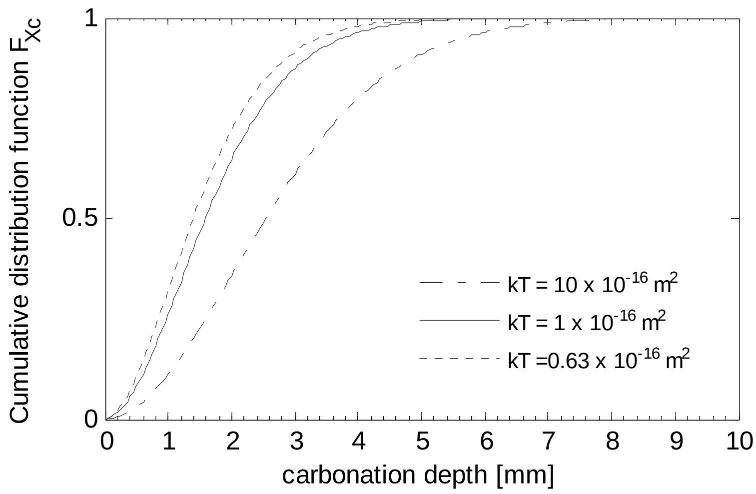

Figure 5. *Cumulative distribution function of the carbonation depth for t* = 1 *year,* $\sigma_{\log_{10}(kT)}$ = 0.4 *and* $\mu_{\log_{10}(kT)}$ = -16.2, -16.0 *and* -15.0*.*

3.4 Computation of service life

For given distributions of the concrete cover thickness and of the carbonation depth, the service life t_{SL} corresponds to the time t for which the probability of failure, as given by equation (17), reaches its maximum acceptable value, $P_f(t = t_{SL}) = P_{f,max}$.

Although there is no major difficulty in determining the service life for any distribution of the concrete cover thickness, for the sake of simplicity, in the following, service life is computed for the case in which it is deterministic, $d_c = d_{c,0}$. In this particular case, the expression for the failure probability becomes

$$P_f(t) = \int_{d_{c,0}}^{+\infty} f_{X_c}(x_c) d\, x_c = 1 - F_{X_c}(d_{c,0}) = 1 - F_c\left(\frac{d_{c,0}}{\sqrt{t}}\right). \quad (20)$$

It is clear from equation (20), that the service life t_{SL} corresponds to the time t for which the term $d_{c,0}/\sqrt{t}$ equals the (1-$P_{f,max}$)-quantile of the cumulative distribution function F_c of the carbonation rate.

For example, approximate values of the (1-$P_{f,max}$)-quantiles have been computed for $\sigma_{\log_{10}(kT)}$ = 0.4, $\mu_{\log_{10}(kT)}$ = -16.2, -16.0 and -15.0 and for $P_{f,max}$ = 2.275% (β = 2). The results are presented in table 2. The value of 0.4 for the standard deviation of $\log_{10}(kT)$appears to be typical for air permeability measurements [9].

(1-$P_{f,max}$)-quantile of the cumulative distribution function F_c [mm/y$^{0.5}$]			
$\sigma_{\log_{10}(kT)}$	$\mu_{\log_{10}(kT)}$		
	-16.2	-16.0	-15.0
0.4	3.95	4.37	6.47

Table 2. *Approximate values of the* (1-$P_{f,max}$)*-quantiles computed for* $\sigma_{\log_{10}(kT)}$ = 0.4, $\mu_{\log_{10}(kT)}$ = -16.2, -16.0 *and* -15.0 *and for* $P_{f,max}$ = 2.275% (β = 2).

Basing on the quantiles presented in the previous table, service life values have been calculated, for example, for a concrete cover thickness $d_{c,0}$ = 30, 40 and 50 mm. The results are shown in table 3.

service life t_{SL} [years]			
concrete cover thickness [mm]	$\mu_{\log_{10}(kT)}$		
	-16.2	-16.0	-15.0
30	58	47	21
40	103	84	38
50	160	131	60

Table 3. *Service life computed for* $\mu_{\log_{10}(kT)}$ = -16.2, -16.0 *and* -15.0 *and for* $d_{c,0}$ = 30, 40 *and* 50 *mm* (*$\sigma_{\log_{10}(kT)}$ is assumed to be* 0.4).

The data indicate, that for a geometric mean of the air permeability of $1.0 \cdot 10^{-16}$ m^2, the service life ranges from 47 years for a 30 mm concrete cover up to 131 years for a 50 mm cover. For a geometric mean of $10.0 \cdot 10^{-16}$ m^2 service life barely reaches 50 years.

Most important, once the requirements about the cover thickness and the desired service life are specified, the method just described can be used to determine upper bounds for the concrete cover air permeability. These can be viewed as compliance criteria when assessing durability of a newly constructed structure. For example, for monumental building structures, bridges and other civil engineering structures, whose recommended service life is 100 years according to EN 1990, the method gives a limiting value of about $0.6 \cdot 10^{-16}$ m^2 for a 40 mm cover.

4. Conclusions

Carbonation and air permeability data were obtained from a 35 years old concrete building in order to study the relationship existing between field carbonation rates and the permeability of the cover layer. The data were analysed by means of likelihood inference. The results of the analysis show that the relationship can be reasonably well described with a model based on the Weibull distribution with a constant shape parameter and a scale parameter which depends upon the air permeability.

The fitted model and the fact that air permeability is found to follow a lognormal distribution were used to derive the time-dependent distribution function of the carbonation depth and to compute service life as a function of air permeability and of cover thickness. The service life computation method presented in the paper is a useful tool for the non-destructive assessment of durability of concrete structures.

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The concept of an engineering-geocryological monitoring system of the highway "Amur" Chita-Khabarovsk

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Abstract

The methodical document «The concept of system engineering-geocryological monitoring of the federal highway "Amur" Chita - Khabarovsk (SEGMA “Amur”) was developed for security of resistance and reliability of federal highway "Amur" during its exploitation. In it are described: the frame the SEGMA "Amur" which is powering up blocks: observation; collecting, handling, analysis, an estimation and storage of the information; the forecast and preparing of protective measures; realization of protective measures; the scheme of operation in time the SEGMA "Amur"; the functional frame the SEGMA "Amur"; a plant engineering-geocryological probes in the SEGMA "Amur"; the complex program of architecture the SEGMA "Amur" called determine an optimum compound and sequence of practical operations on architecture and operation the SEGMA "Amur"; the plan of realization of this program SEGMA "Amur".

Keywords: permafrost, highway “Amur”, engineering-geocryological monitoring

1. Introduction

The federal highway "Amur" Chita - Khabarovsk is one of the largest modern constructions in Russia. Its construction started in 1978. The road pitch-grouted macadam shall be completed in 2007 and paved with asphalt in 2010. It has a length of 2165 km and traverses from west to east Transbaikalia and Priamurie - terrains with rather heterogeneous geomorphologic, geology-tectonic and climatic conditions that in turn predetermine significant dissimilarity of engineering-geocryological conditions of a route. During construction and operation of the road considerable changes take place in frozen environment and unfavorable engineering-geocryological processes and phenomena occur like thermokarst, heaving, solifluction, thermo erosion, ground ice mound etc. To ensure sustainability and reliability of “Amur” highway during its operation the following is required: timely detection of regularities progressing in the frozen environment of the route, systematic monitoring of their dynamics and cryogenic impact on elements of the road, carrying out of protective measures. It would be highly efficient within the framework of engineering-geocryological monitoring of highway “Amur” (SEGMA “Amur”) to provide constant monitoring, assessment, forecast and management of engineering-geocryological processes on the route.

2. The scheme of frozen-geomorphologic zoning of the route and large-scale engineering-geocryological cuts in key road sections

The basis of spatial presentation on engineering-geocryological route conditions of “Amur” highway makes up a general lay-out of frozen-geomorphologic zoning of the route at 1:1000000 – 1: 2000000 scale and large-scale cuts in the key sections of the highway in the form of engineering-geocryological schemes of micro-zoning at 1:8300 - 1:20000 scale, as well as engineering-geological longitudinal profiles along the axis of highway and the charts with main engineering-geocryological features of the section.

The scheme of frozen-geomorphologic zoning of the route is devised in accordance with territorial administrative division through which the highway traverses and comprised of 3 parts: Chita province (0-794 km) Amur region (794-1811 km) and Jewish province (1811-2165 km). The scheme singles out 6 geomorphologic regions: Daurskoe vault elevation, East-Transbaikalian depression, Prishiklinskaya mountain and valley country, Amur depression, Bureinsko-Amur plicate and lumpish mountain region, Sungari-Amur depression and 5 frozen zones: continuous permafrost zone, broken insular permafrost zone, insular permafrost zone, infrequent permafrost zone, zone of deep ground seasonal frost penetration. All above geomorphologic regions and frozen zones are characterized by 16 large-scale cuts and placed along the highway in the following way: 7 cuts (km km 72-75, 112-115, 332-335, 348-350, 389-392, 536-539 and 757-760) – Chita province as the most complex one regarding its frozen-geological zones. 7 cuts of Amur part as the most stretched one (km km 882-885, 905-908, 1060-1063, 1128-1131, 1370-1373, 1441-1444 and 1626-1629) and Jewish region as the least extensive and easy as far as frozen-geological conditions are concerned.

The scheme of frozen-geomorphologic zoning of highway and its key sections are the basis for the spatial placement of engineering-geocryological monitoring network on this very extensive road.

3. Development of risky engineering-geocryological processes on the highway

The highway has not been completed yet but many sections of the road are being damaged due to engineering-geocryological processes. Here are two typical examples.

3.1 Deformation of highway on a crossing over the valley stream Chichon, 247 km

The section of highway “Amur” on a crossing over the valley stream Chichon, 247 km was put into operation in August, 2000. It has had continuous deformations since May 2001 and assumes dangerous nature (fig. 1).

Figure 1. *Chita-Khabarovsk highway deformation, 247 km, due to degradation of icy permafrost soils in the base, before the innovation repair, July 2006*

Road sagging at some places came down to about 2 meters deep in spite of recurring soil fill up and profile leveling. Transverse and diagonal cracks with a width of 15-20 cm are seen on the traffic way, on the roadsides, fill slopes as well as on the surface directly adjoining the mound. This section is exposed to accidents. The speed is limited to 40 km/hour however the design speed is 100 km/hour. Deformation of roadbed happens due to degradation of icy dispersed permafrost soils in its base and due to the effect of thaw impact and heat penetration from the sun rays as well as due to summer precipitation on bare mound from draining soil. At the same time the chances are high of a sudden loss of mound stability, sliding of roadbed or springing up of holes on traffic way. Since in the base of the road there is still 15-20 m of perennial ice left, for the most part icy, collapsible and fluid when thawing, the process of permafrost degradation and deformation of the road accordingly in the existing condition may continue for ten and maybe hundred years and that proves the experience of Transbaikalian railroad that placed in parallel with the federal highway “Amur”.

In 2006 an attempt was made to stabilize the breakdown section by traditional way without any sort of appropriate engineering-geocryological survey or forecast on subsequent development of unfavorable processes. By way of office studies the conclusions on suffosion processes were drawn and the following measures drafted: blind longitudinal drainage from the bottom side of the mound, cutting of drain from hillside and coating of the northern slope by reinforced composition from highly siliceous and carbonate minerals. It cost around 10 million rubles however positive effect was not reached (fig. 2).

Figure 2. Section of highway "Amur", km 247, 23 months after innovation repair, August 2008

Such situation was expected since suffosion was absent at the section as well as underwater currents where drainage ditch was set up. Here it is required to develop and implement stabilizing measures aimed at discontinuance of further development of permafrost degradation in the base of highway or the other way round to undertake measures on quick forced thawing of ice mass and simultaneously filling up weak spots in the base by non collapsible soil mass.

While a project of highway was being developed, the second method of design was adopted that stipulated thawing of permafrost soils of the base by a forecasted margin of structural settlement or replacement of icy collapsible soil when the soil thaws, for non collapsible soil on a rated depth where soil thawing happens.

The BAM experience showed where replacement of soil under track formation was carried out down to 2 m and in Alaska the works carried out on roadbed soil replacement down to 6 m. The second method of design is not acceptable, if the depth of icy thickness does not give any chance of its full cutting during construction of roadbed. Fractional cutting of icy soil and its replacement with drainage soil only stimulates growth of thermokarst in the base of roadbed and causes its continuous deformation. Thus reducing reliability and safety of the highway and augmenting operational costs.

Similar to the track formation if in due time there is no chance to cut out entirely the icy soil sections then the first method of design is required to apply for the roadbed and preserve icy soils of the base for the entire term of road operation and at the same time to develop stabilizing measures.

3.2 Slope deformation of deep groove at 390 km of the highway

The length of groove is about 800 m, maximum depth up to roadbed is about 40 m, the width at the bottom is about 33.5 m, maximum width at the top is about 106.5, orientation is about 70^0 to the east – north-east. Groove occurs in granites of different degrees of weathering and jointing (from very hard, non-mouldering, jointy and not too so hard, mouldering and intensively jointy) covered by loose sediments (crumbly soil with clay sand and loamy gouge, loamy sand and loam) with thickness 1.7-3.6 m. The entire soil mass was frozen in natural conditions, the depth of seasonal soil thawing was 2-2.7 m.

The initially designed groove steepness of slope was 1:1.5 in the upper part, height 2-4 m, composed of loose sediments; in the middle part, height 3-36 m composed of average and reduced strength granites, mouldering, cracky and intensively jointy.

However during construction, groove slopes, especially the slope of southern exposition, began to strongly deteriorate due to the post cryogenic weathering and started to crumble and slide. All this resulted in interruptions in the construction of groove. The designer had to carry out some adjustments in the roadbed groove design; to decrease the steepness of slope and arrange shelving. This resulted in cost increase of the groove by 20 million rubles.

However these measures do not resolve the problem. Just on the contrary they may force post cryogenic weathering of bedrock since more atmospheric precipitation penetrates into a wider groove and eventually can result in the increase of soil mass volume heaving at the slopes of a groove. Weathering of bedrock removed from the groove and dumped, may in the course of time turn into heaving soil due to the increase of its dispersity.

Icings also develop on the highway (fig. 3) as well as slope erosion of the groove and mounds, heaving and freeze fracture cracking.

Figure 3. *Icing on highway “Amur”, km 89, April 2009*

This requires constant supervision, assessment, forecast and management of highway engineering-geocryological processes development and protection from hazardous impacts.

4. Concept of engineering-geocryological monitoring system for the “Amur” highway

Only the engineering-geocryological monitoring system for the “Amur” highway (SIGMA “Amur”) shall ensure constant supervision, assessment, forecast and management of highway engineering-geocryological processes development and provide for stability of roadbed and engineering structures.

In 2006 TransIGEM developed and passed over to Rosavtodor a concept of SIGMA “Amur”.

The following is developed and described:

- Structure of SIGMA “Amur” includes: information gathering, processing and analysis of information, assessment and information storage; forecasting and protective measures; protection (implementation of protective measures);

- The operating scheme of SIGMA “Amur” provides for a number of regulated procedures arranged into cycles of data to be received, assessment of hazardous engineering-geocryological processes, forecasting their future development and management of unfavorable processes;

- Operating structure of SIGMA “Amur” consists of several subsystems designed for different purposes: hierarchical, project monitoring and operating subsystems, productive work, scientific-methodical and technical support;

- Subject of SIGMA “Amur” engineering-geocryological inquiry consists of three interrelated parts: geology-geographical conditions of highway, permafrost conditions and highway conditions;

- The complex program of SIGMA “Amur” organization, defines optimal structure and consistency of practical operations regarding organization and functioning of SIGMA “Amur”.

- The plan to implement a complex program with the aim to set up SIGMA “Amur”. The program has three stages: preliminary stage, set-up of information database and the stage of SIGMA “Amur” operation;

- Proposals on organizational support of SIGMA “Amur” operation

Proceeding from the concept described above it is necessary to devise a project to set up SIGMA “Amur”. The project shall stipulate all the organizational, financial, methodical and technical aspects of engineering-geocryological support for operation of the “Amur” highway, including the current maintenance, repair, major overhaul and reconstruction.

Taking into account that dozens of years have passed since the survey was made and it took nearly three decades to put the federal highway “Amur” Chita-Khabarovsk into operation. Now it is required to carry out special engineering-geocryological research work and to define actual geocryological situation in the body of the road, in the roadbed base, right-of-way space, on the adjacent territory and on the sites with engineering structures. With the help of aerial photography, geophysical and engineering-geocryological surveys, boring, through operating monitoring, laboratory and office studies the following ought to be done: to define composition, cryogenic texture, physical-mechanical and thermalphysic properties, spread, temperature condition, conditions of occurrence, thickness of seasonal soils, permafrost soils and seasonally thawed ground as well as development of cryological processes and phenomena. Analysis based on the results of received and preceding survey data ought to define common and specific regularities of formation and development of geocryological conditions depending on geology-geographical factors, structural and technological peculiarities of the highway elements.

Thereupon with the help of mathematical and physical simulation in combination with thermotechnical estimates, the geocryological forecasting must be carried out for the purpose of receiving scientifically substantiated, concrete in time and space understanding on the character of probable change in engineering-geocryological situation of the highway due to natural processes and man-caused impacts during construction and operation of the highway. The forecast of changes in the frozen ground conditions must contain characteristics of temperature conditions spread, conditions of occurrence, thickness, cryogenic texture, physical-mechanical and thermalphysic properties of seasonal and permafrost soils, the depth of seasonal thawing and the depth of soil freezing, development of cryogenic processes and phenomena. Those in their turn shall become the benchmark data for developing measures on management of engineering-geocryological situation with the aim to set up optimal conditions of highway operation and to conserve nature on the adjacent territory.

5. Conclusions

The earlier the creation and operation of the engineering-geocryological monitoring system of Chita-Khabarovsk “Amur” highway shall be initiated, the more reliable and safe it will be thus minimizing non-productive outlays during its operation.

Development of a remote condition assessment system for road infrastructures

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Abstract

This paper describes a Remote Collaborative Visual Inspection System for integrated management by linking digital movie captured by a running vehicle and online road drawings. The newly developed road condition assessment system consists of commercially available on-board high-resolution video cameras during the visual inspection of road pavements and road appurtenances and a Web connection system. The system enables users to select a road section in a road register on an on-screen map and visually observe not only pavements but also road facilities, slopes, the state of vegetation, and road-occupying structures. The system, therefore, can be expected to help reduce visual detection failures compared with conventional visual observation from moving vehicles and make highly objective evaluation possible through observation by two or more persons. By using image data, the system also provides basic data that can be used for not only maintenance but also road planning.

Keywords: road infrastructure, digital movie, condition assessment, online drawing, diagnosis

1. Introduction

There is concern about the growing cost of maintenance, such as reconstruction and repairs, of a large stock of road infrastructure accumulated during and after the period of rapid economic growth. In view of the aging of infrastructure including road facilities and of the needs of society, there is growing demand for reasonable maintenance including preventive maintenance under tight budget and human resource constraints [1].

For road pavements, the Maintenance Control Index (MCI) is widely used in Japan as an index for asphalt pavement damage [2]. MCI parameterizes the cracking ratio, roughness and rutting depth, but it can also be used as an index based on two attributes or one attribute. In the United States, the present serviceability level of pavements is expressed with AASHTO's Present Serviceability Index (PSI) [3]. Research comparing this index with other indices is also underway [4]. The World Bank has proposed the International Roughness Index (IRI) as an indicator, focusing mainly on ride quality, of the roughness of road surfaces including but not limited to asphalt pavements [5, 6].

For the indices mentioned above, the soundness of road pavements is usually evaluated by using a road inspection vehicle. A road inspection vehicle is capable of accurate quantitative evaluation, but its initial cost and operating cost are usually relatively high, and the frequency of use of road inspection vehicles tends to be low. There are also constraints due to the road width, radius of curvature, slope, etc., that can be measured with a road inspection vehicle.

Besides the pavement mentioned above, there are many road elements that should be checked regularly, such as road appurtenances, filled and cut slopes. The assessment of non-pavement elements, however, relies in many cases on qualitative and subjective judgment such as visual inspection from maintenance patrol vehicles and information provided by drivers and local residents. It is not uncommon, therefore, that considerable amounts of time and cost are spent before repair or other maintenance measures are taken.

In this study, views from a maintenance patrol vehicle were recorded to supplement visual inspection from the vehicle and obtain objective and repeatable inspection results. The purpose of the study is to develop a system for visual assessment of the present state of not only pavements but also road structures including appurtenances, slopes and vegetation (*Remote Collaborative Visual Inspection System*).

2. Present state of maintenance of road structures

2.1 Maintenance at prefectural level

The Yamaguchi Prefectural Government, for example, is responsible for a road network with a total length of 3,388 km (see Figure 1). In Yamaguchi Prefecture, road

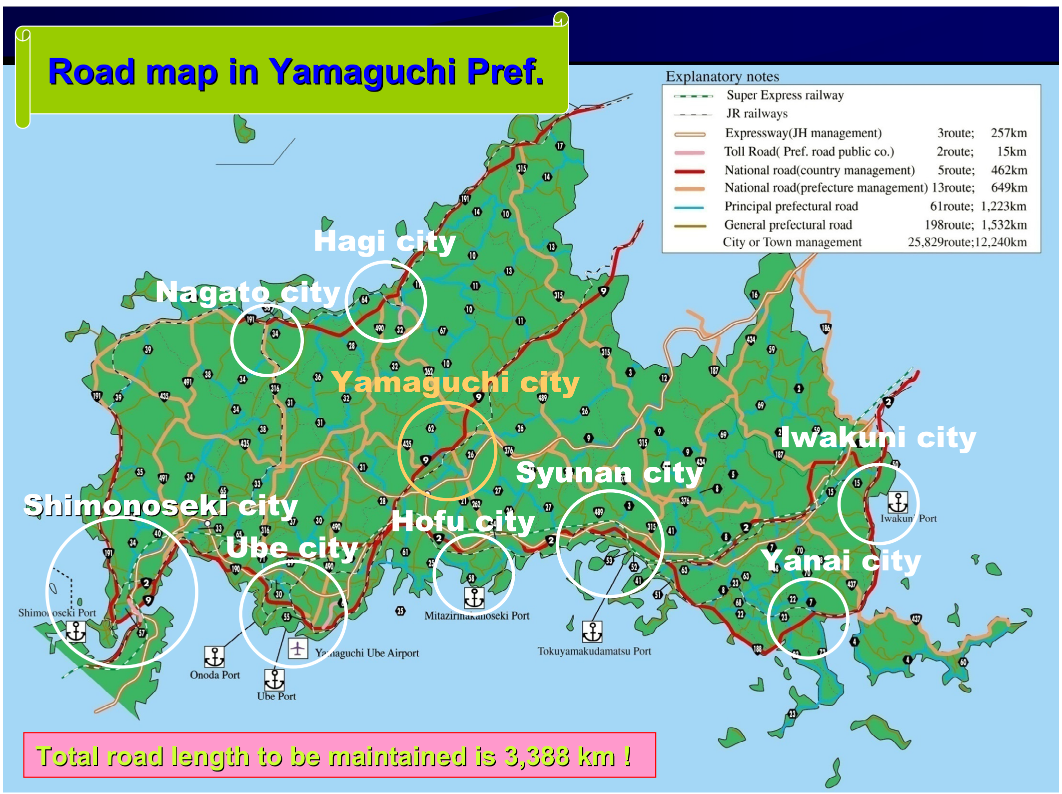

Figure 1. *Road network managed by Yamaguchi Prefecture and total road length.*

sections are classified according to the degree of importance of each road section, and road inspection vehicle surveys and visual surveys by pavement contractors are conducted in seven-year cycles. The survey results are documented in specified formats and used by maintenance-related departments. Daily maintenance patrol of roads is performed by contractors, and each road section is assessed by one evaluator. Pavement conditions are diagrammatically recorded on paper in the road register. Since, however, these diagrams are difficult to relate to the actual road locations, it cannot be said that the diagrams are being used effectively.

Information indicating the present state of roads includes the road register, the preparation of which is required by the Road Act. In the road register of Yamaguchi Prefecture, a 1/1000-scale plan view of a 500-meter-long road section is shown in the upper half of each data sheet, and the road length, road width and the radius of curvature are shown in the lower half (see Figure 6). The longitudinal slope, however, is not indicated. Each data set kept at each local office consists of one set of A2-size Mylar original drawings for a road section, one set of their paper copies, and hard covers to protect the Mylar and paper drawings. To use register data, usually, copies are made, on an as-needed basis, of necessary data sheets in the bound volumes. More efficient management of information in these registers is being hoped for in order to respond to public complaints or explain project details promptly.

2.2 Road structure data in electronic form

Research and implementation efforts are underway to digitize and standardize data on roads and road appurtenances. Examples are JHDM (Japan Highway Data Model) [7], which has been developed by NEXCO (former Japan Highway Public Corporation), CAD-based LandXML [8] and IFC-Road [9], which is a standardization effort of IAI (International Alliance for Interoperability). Huge amounts of time and cost would be required, however, if local governments that manage information on many existing roads on paper were to standardize their registers by using the data models mentioned above. There is a need, therefore, for a method of seamless transition from the present maintenance scheme to a scheme based on the use of information in electronic form.

3. System development

3.1 Sharing images obtained by maintenance vehicles and road register data

By linking and sharing digitized road register data and corresponding images captured by road inspection vehicles, this study aims to enable two or more evaluators to identify and locate road and road facility damage and roadway problem areas in the captured images in order to enhance the objectivity of assessment and reduce detection failures. Because images captured by road inspection vehicles can be evaluated visually, they make it possible to make effective use of the advantages of sharing. The digitization of register data greatly contributes to labor saving because the management of information recorded on paper is no longer necessary.

3.2 Digitization work flow

Information recorded on paper such as existing road registers and summery plots and district maps in registers was scanned and saved in the PDF format. Images captured with high-definition cameras were saved in the fairly common MPEG-2 format. Figure 2 illustrates the digitization work flow.

It is believed that in the digitizing effort in the coming years, the incorporation of road register data into a CAD system and the development of databases of register data items will be essential. This study, however, goes only as far as digitizing information by the method mentioned above in order to assist and enhance efficiency in visual inspection with a relatively small amount of effort and without creating excessive workload for maintenance personnel.

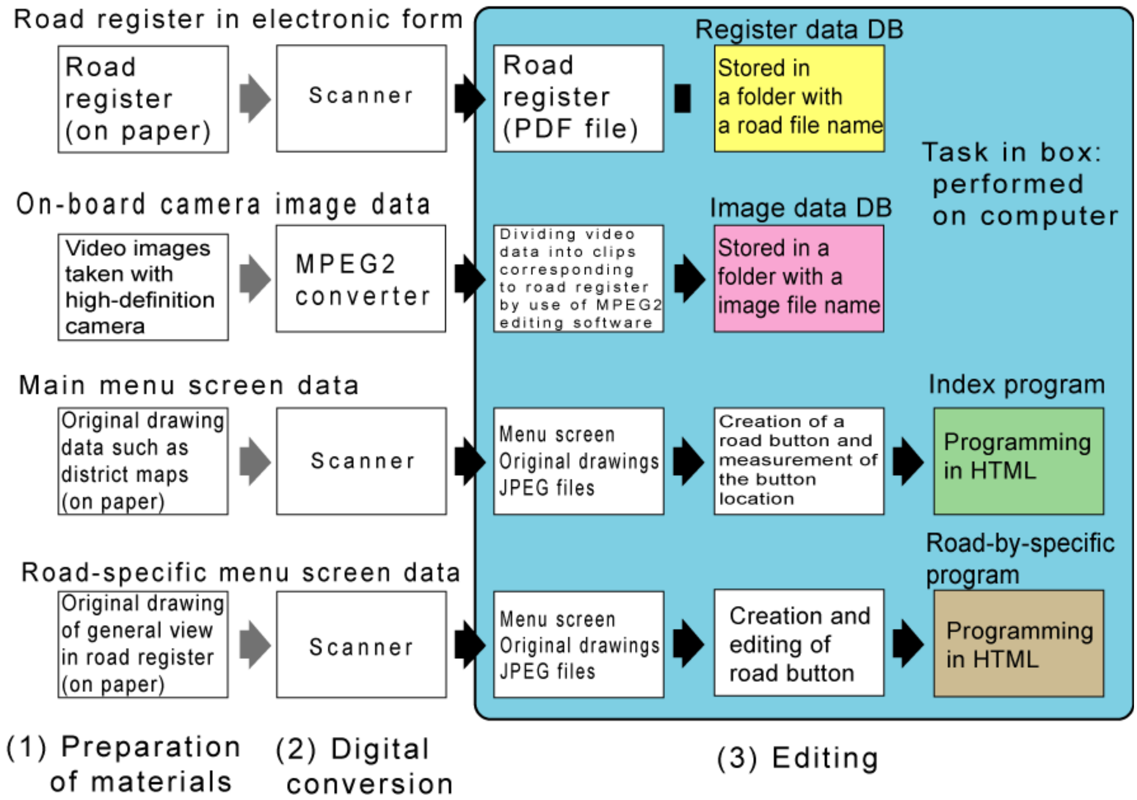

Figure 2. *Procedure for digitizing road information.*

3.3 Data binding

As shown in Figure 2, HTML (HyperText Markup Language), a widely used Web page scripting language [10], was used to relate the digitized data and create the user interface. HTML was used because hyperlinks facilitate data linking (e.g., linking road register data and on-board camera image data) and future extension into a Web-based system including database implementation. In the case of a relatively small-scale data system like the road condition assessment system developed in this study, hyperlinks can be maintained with relative ease through HTML modifications.

3.4 Data hierarchy

The road condition assessment system consists of three levels as shown in Figure 3. The first level is the menu screen of the system that displays three roads to be managed. The second level shows road-by-road registers. At the third level, road registers and captured images linked to the register data are stored. Users can select a road on the menu screen (Figure 4), select the number representing the road register at the second level (Figure 5) to display the road register data (Figure 6) or captured images (Figure 7). In Figure 5, black boxes (hand-shaped pointer 1) represent links to the road register; the red boxes (hand-shaped pointer 2) represent links to the images captured from a vehicle running from the start point and the end point corresponding to the register data; and the white boxes (hand-shaped pointer 3) represent links to the images captured from a vehicle running from the end point to the start point corresponding to the register data. The red (hand-shaped pointer 4) and white triangles represent links to the images captured from a vehicle running from the start point to the end point of the road and from the end point to the start point.

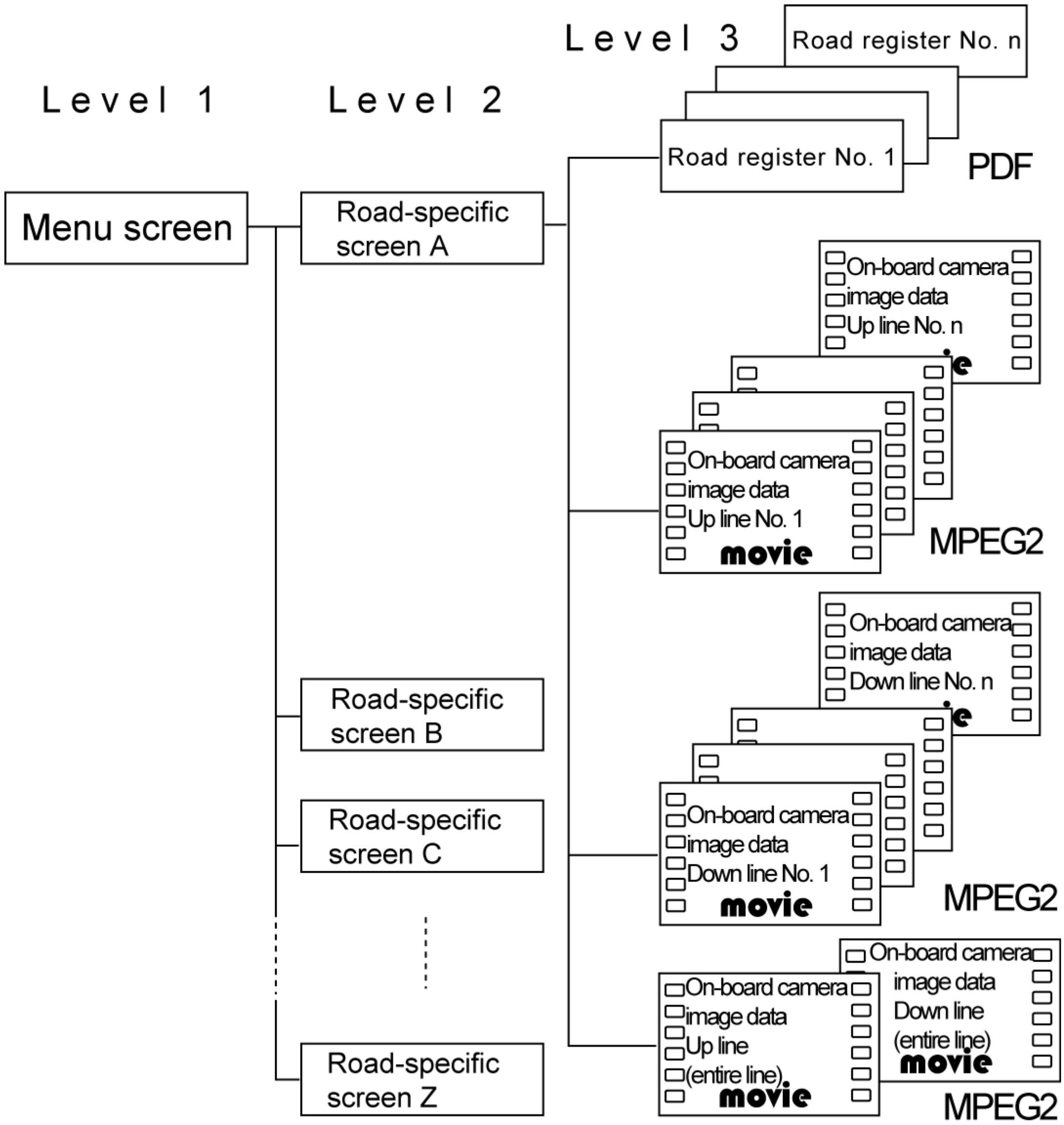

Figure 3. *Data hierarchy.*

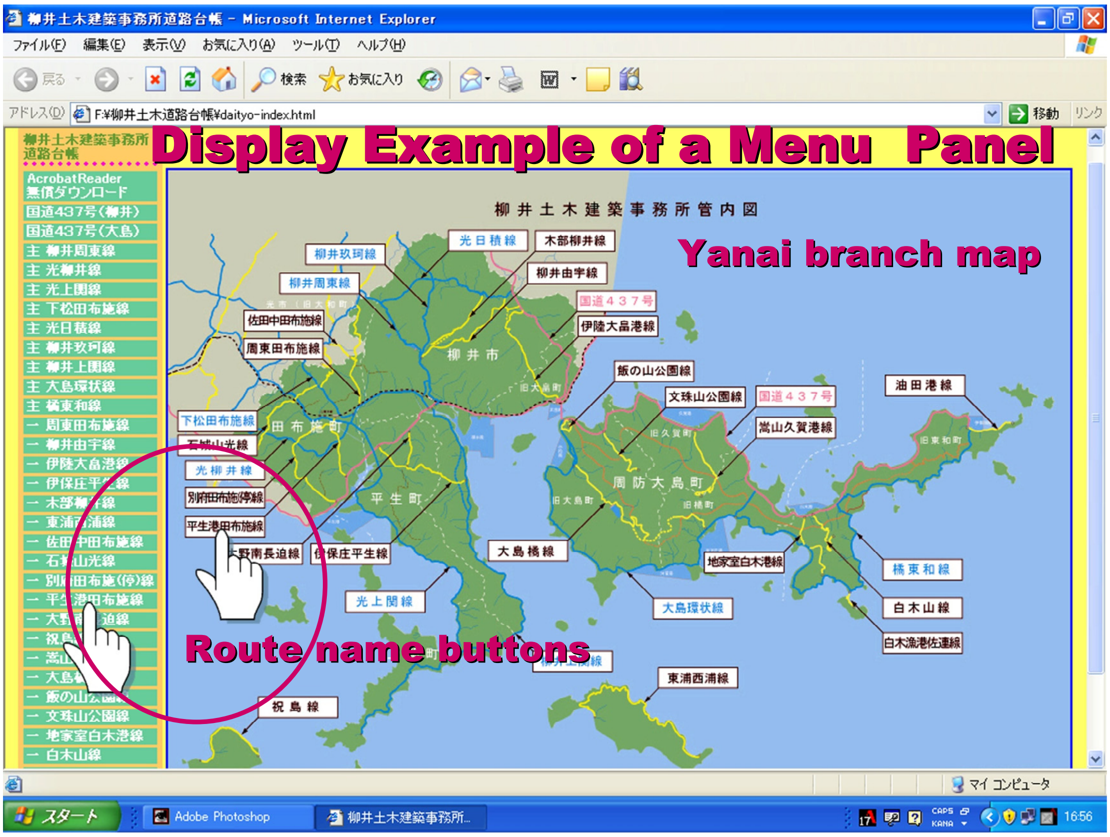

Figure 4. *Example of road menu (Level 1).*

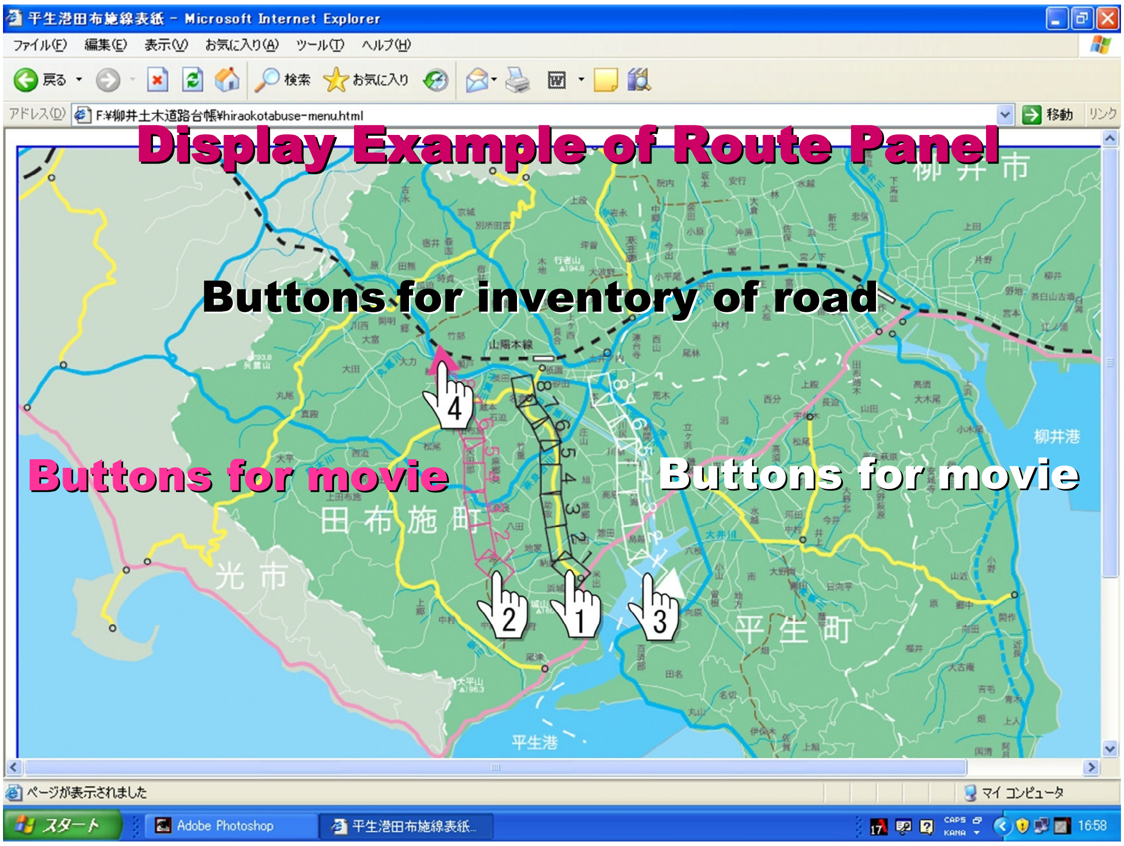

Figure 5. *Example of road-specific menu (Level 2).*

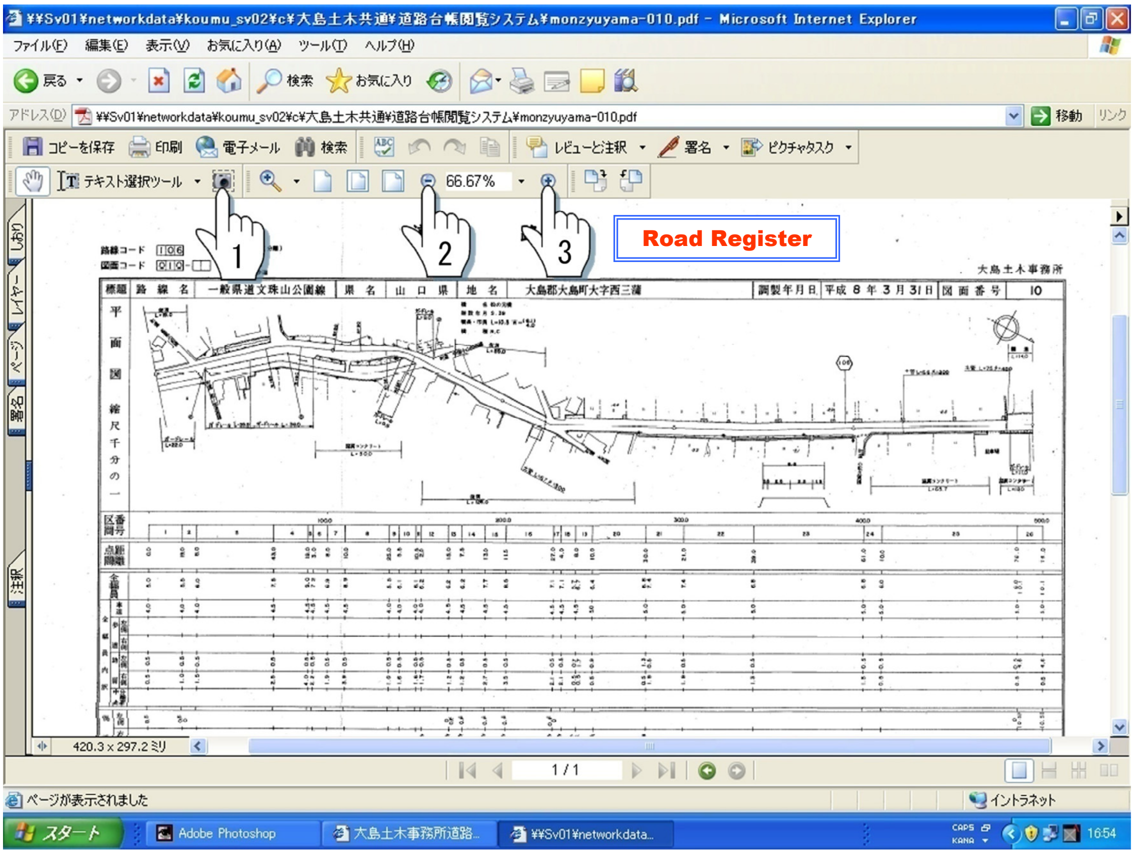

Figure 6. *Example of road register screen (Level 3).*

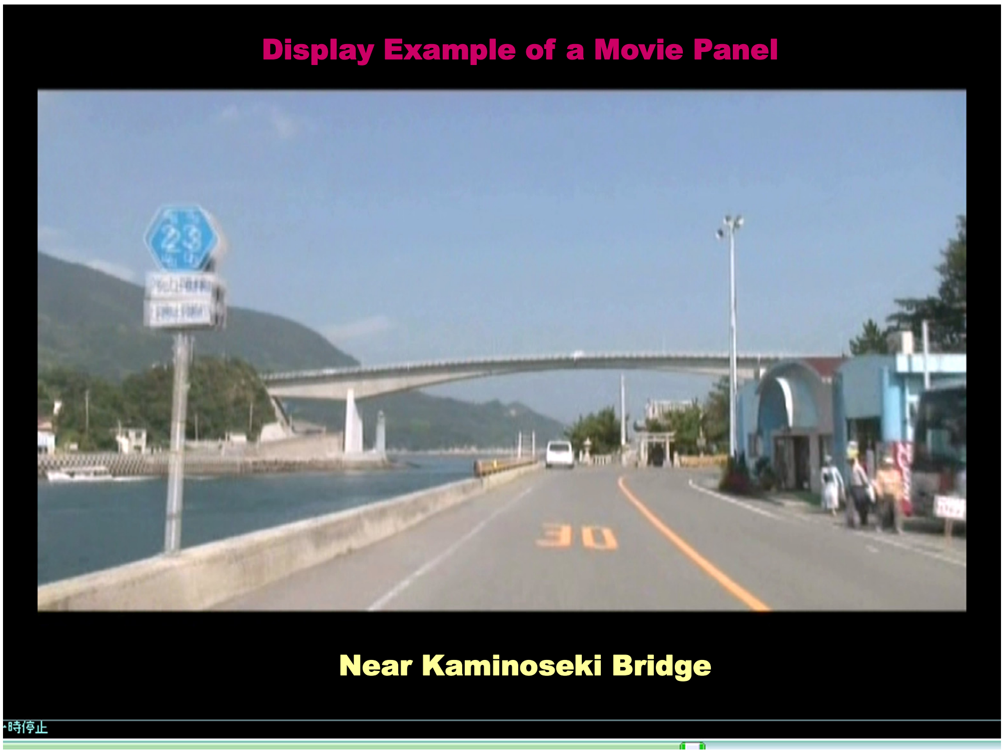

Figure 7. *Example of on-board camera image (Level 3).*

4. Image acquisition and links to road register data

4.1 Image acquisition

To obtain images from a vehicle, a commercially available high-definition video camera, a monopod for supporting the camera, and a voltage converter for 12V DC connection. To prevent the windshield from reflecting light, the dashboard was covered with black cloth. Figure 8 shows the setup for video shooting. During video shooting, the vehicle speed was kept at 50 km/h or less. In curved road sections, the camera was turned sideways from direction A to direction B so that the center of the roadway stayed at the center of the image frame (see Figure 8). The captured images were converted to MPEG-2 for video viewing convenience. The use of higher-resolution formats will also be considered in future studies.

Figure 8. *Setup of on-board video camera.*

4.2 Linking images and road register data

Video clips corresponding to road register data were prepared from the captured video data by using video editing software and visually interpreting the images mainly by the human eye. The video clips and road register data were related through HTML files showing road maps. The tasks at this stage consisted mainly of video editing and data linking performed manually. The next goal, therefore, is to shorten the time required for editing by performing GPS data measurement simultaneously to link video data and time during video shooting and pick up the time at which the start and end point coordinates in the road register are passed.

5. Use and evaluation of the system

5.1 Example of use of road register and image data

Figure 9 is a screenshot showing an example of a system screen. In this example, the screen displays the road register data, and a video clip showing the corresponding road section is being played back by media player software. The video images were captured by a vehicle moving from right to left of the map, and the image in Figure 9 shows the area on the near side of the municipal road and the intersection in the left half of the plan view. The road-specific menu screens for the roads in Yamaguchi Prefecture have already been completed, and the road register data for all roads in the prefecture can be viewed on the system. Video image data for the roads managed by "Yanai" branch office of the Yamaguchi Prefectural Government are already available, and the preparation of video image data for the roads managed by "Ube" branch office of the Yamaguchi Prefectural Government is currently underway. The total disk space needed to store image data for all roads in the prefecture is estimated to be about 1.0 TB. It is relatively easy to develop a highly redundant Web-based system by using a distributed data server system.

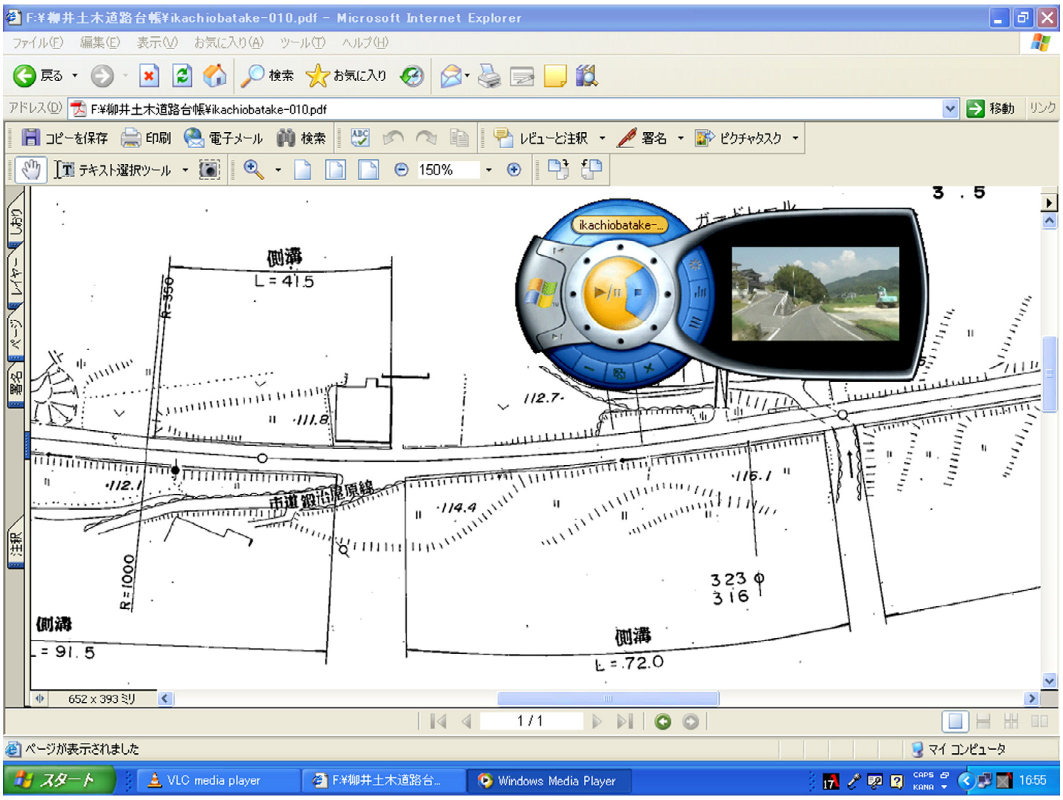

Figure 9. *Using the system.*

5.2 Proposed approach to pavement asset management

Figure 10 shows a sample workflow for pavement repair by use of the road condition assessment system. As the first step, video images and audio clips are played back (see Figure 7), and pavement damage areas are identified by the eye and ear of the estimators. As the next step, field surveys of the identified damage areas are conducted to identify the areas to be repaired and prioritize the repair needs. Because of budgetary constraints, the prioritization of pavement maintenance needs is essential. The authors, therefore, propose that damage areas identified through field surveys be prioritized into three repair priority levels, namely, “red”: urgent repair needed (MCI < 3, cracking ratio: 30% or more, rutting depth: 30 mm or more); “orange”: repair needed (3

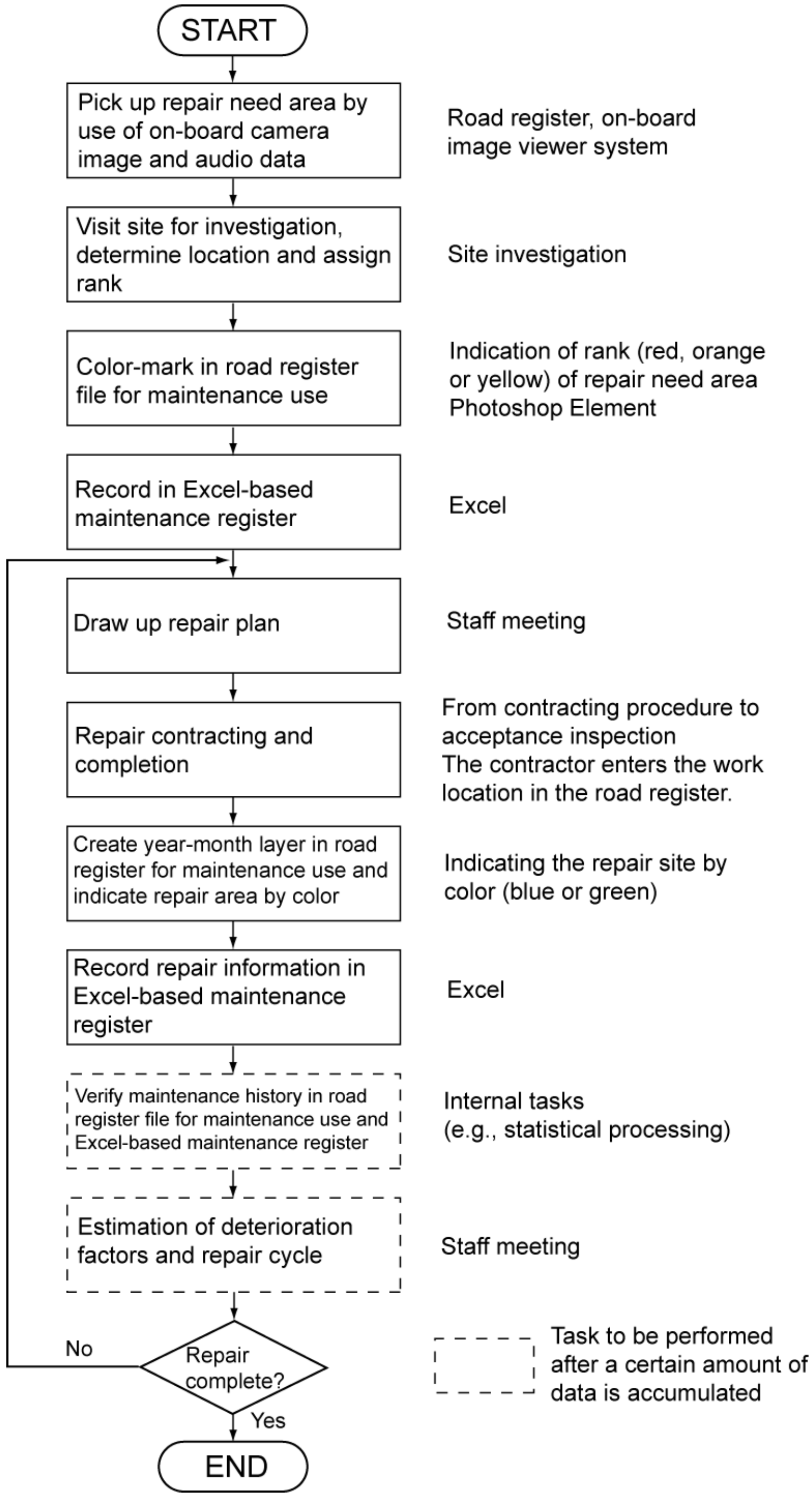

Figure 10. *Example of workflow for road pavement repair.*

< MCI < 5); and “yellow”: monitoring needed (MCI $\approx$ 5, cracking ratio: about 10%, rutting depth: about 20 mm). The next step is to color-mark the damage areas on the road register data screen as shown in Figure 11 by using imaging processing software designed mainly to handle images as raster data.

In this example, the flow of maintenance work using image processing software is explained. An advantage of this method is that the layer capability of the software can be used to store repair history data. To perform statistical processing, registers using the spreadsheet software Microsoft Excel are also created. Layer capability may be thought of as a stack of tracing paper sheets. A repair site is color-marked on the tracing paper sheet corresponding to the time of repair, and a number of "tracing paper sheets" can be superimposed for viewing.

After a repair-need area is indicated by color, the information is entered into a repair-need register using the table shown in Table 1(a). The information thus collected is put together, and a rehabilitation plan is drawn up on the basis of the pavement rehabilitation budget. For the purpose of explanation, it is assumed here that the repair-need area is repaired over a period of two years. The repair work is contracted out in 2006. Upon completion of the repair work, a 2006 layer is defined as shown in Figure 12, and the layer is color-marked to indicate the repair area (light blue in this example) and repair information is entered in Table 1(b). This concludes the information management procedure for the first year. In 2007, after the remaining part of the repair-need area is repaired, a 2007 layer is defined as shown in Figure 13, and the repair area is indicated by color (green in this example) and the repair information is entered in Table 1(c). This concludes the information management procedure for the second year.

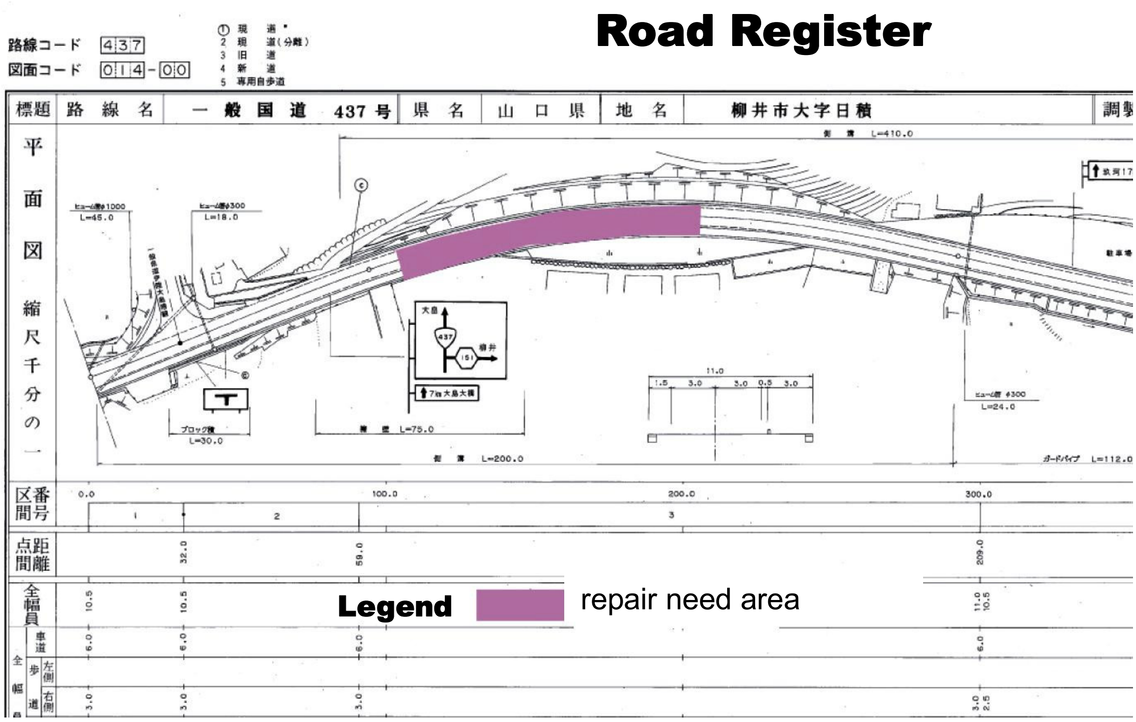

Figure 11. *Repair need area map.*

Table 1. *Example of pavement repair register*.

(a) Repair need register

Road code number	Register number	Area number	Year	Pave-ment area	Resurfac-ing	Overlay	Patch-ing
437	14	1	2006	100	0	100	0

(b) 2006 pavement repair register

Road code number	Register number	Area number	Year	Pave-ment area	Resurfac-ing	Overlay	Patch-ing
437	14	1	2006	70	0	70	0

(c) 2007 pavement repair register

Road code number	Register number	Area number	Year	Pave-ment area	Resurfac-ing	Overlay	Patch-ing
437	14	1	2007	30	0	30	0

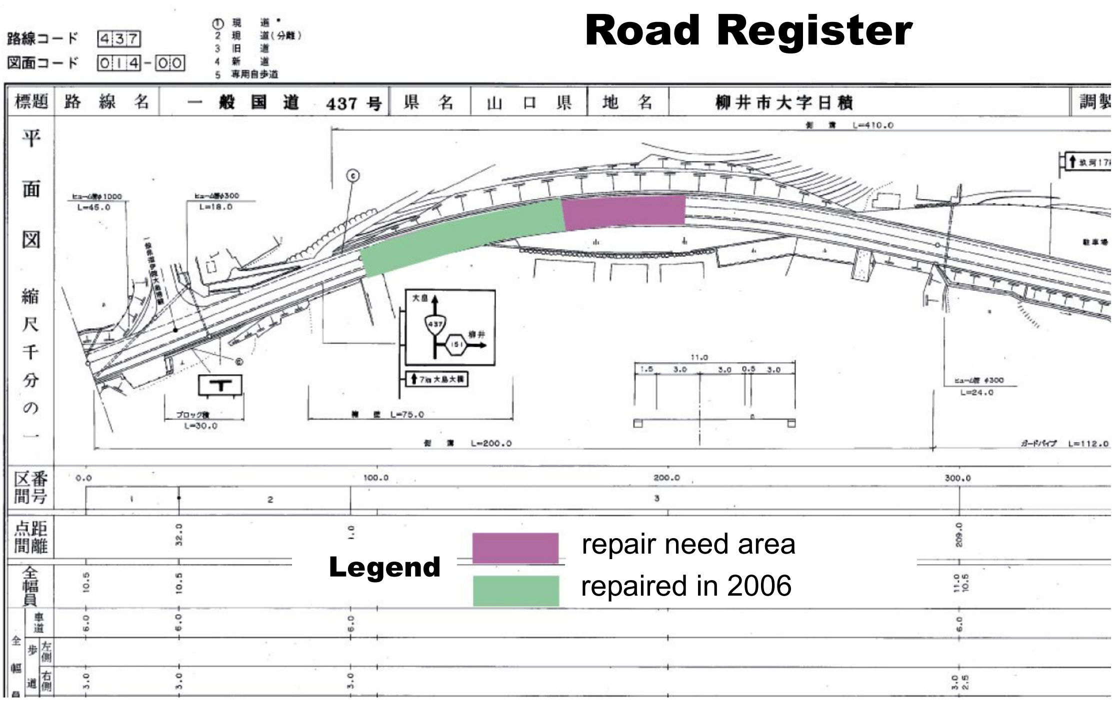

Figure 12. *2006 repair area map.*

The procedures described above are repeated every year. As repair information is accumulated, statistical processing of pavement repair information becomes possible. Because colored data entered in the road register are accumulated in layers as shown in Figure 14, the repair history can be visualized. Drawing management can be made easy, therefore, by having the contractor submit road register data indicating the repair area after completion of the repair work.

Statistical processing of data makes it possible to estimate repair cycles and discover structural problems of roads. By updating the image data periodically, namely, once a year, and storing and comparing image data, changes in the condition of road surfaces and road facilities over time can be determined. This method is sufficient for the

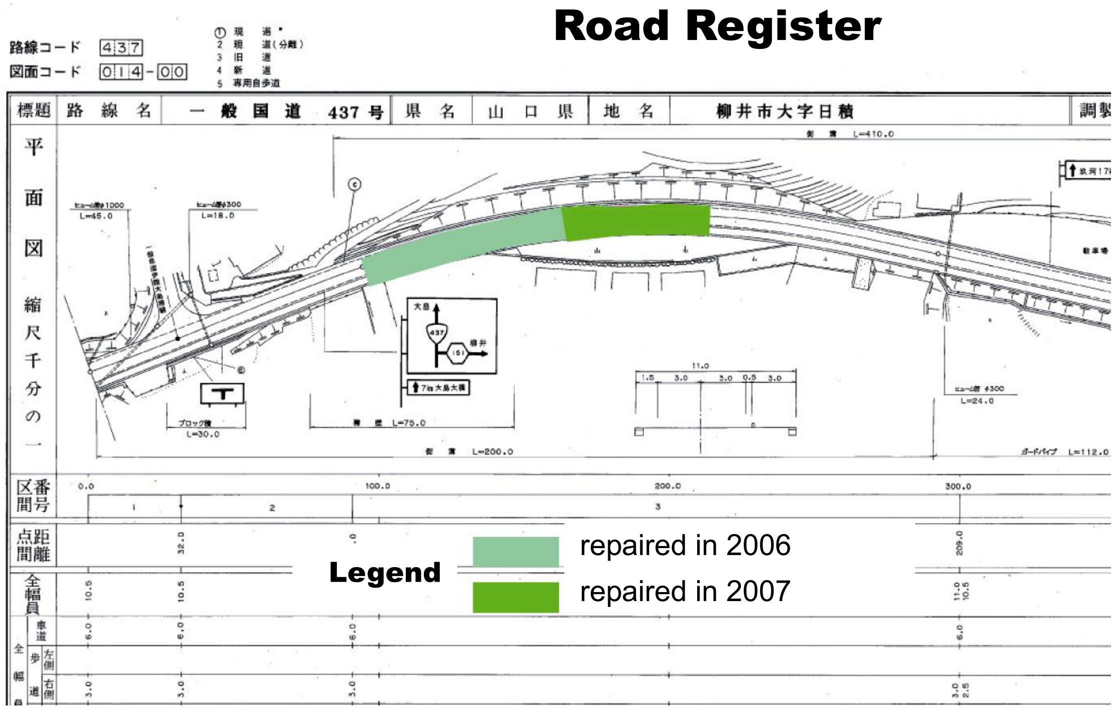

Figure 13. *2007 repair area map.*

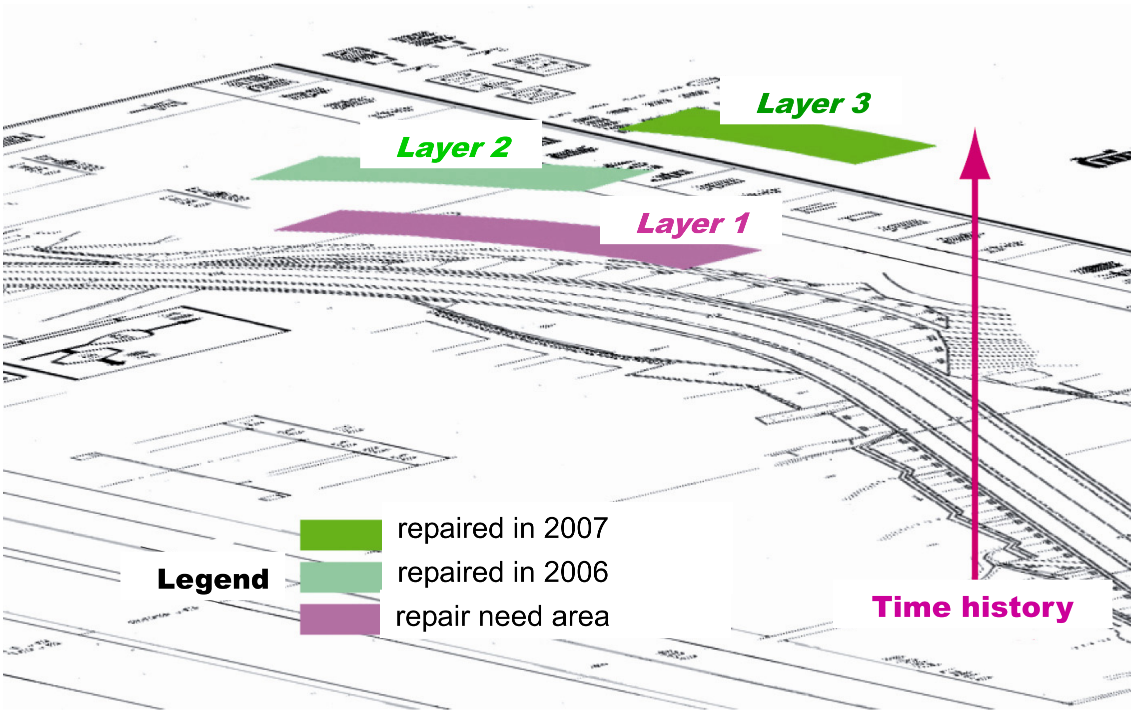

Figure 14. *Example of layered view.*

management and monitoring of a relatively small road network. For data that will increase in the coming years, however, it will be necessary to carry out system extension into a repair history database system linked with a geographic information system (GIS), instead of using map image files and spreadsheet software. It is believed, however, that a transition to a large-scale server-based system will be easy because design schemes for the management of map data, video images and repair history data have already been developed in this study.

5.3 System evaluation

After the road condition assessment system went into operation at the “Yanai” branch office of the Yamaguchi Prefectural Government, the maintenance and construction department personnel who actually used the system were interviewed to hear their views. The results can be summarized as follows:

[**Complaint handling**]: When the maintenance and construction personnel received complaints by phone, they were able to talk about the complaints while viewing the images of the roadside areas concerned. This made it possible to prepare for site investigation, take appropriate and timely measures and record site information and complaint details easily in the road register.

[**Easy operation**]: The district map can be called up by one click of the mouse, and a click on the desired road opens the road register, and, if desired, images corresponding to the road register page in question can be viewed. The simple operation and functions are easy to understand and operate. The video data for one road section (500 m) takes only 30 to 40 seconds to play back. Thus, the system is stress-free, and video data can be paused for examination of details.

[**Shorter travel time**]: Site investigation is sometimes difficult, for example if the problem area is located on a remote island. The system, therefore, is useful.

[**Approval support**]: The system is useful because site conditions can be checked in connection with the approval procedures related to the use of road areas, road work, etc. Another advantage is that prior to boundary confirmation, site conditions can be viewed in advance.

[**Improved accuracy of register data**]: Register data can be easily checked at the desktop at the time of updating. As a result, the accuracy of register data has improved.

[**Disaster response support**]: In the event of a disaster, images showing the pre-disaster road conditions were easily made available because image data had been digitally archived.

Thus, overall, the interviewees found the system useful in performing maintenance tasks and collecting information on site conditions and had positive impressions of the operability of the system.

A survey on the frequency of use of the system revealed that the maintenance personnel used the system every day. The likely reason for this is as follows. Figure 15 shows a breakdown of public complaints about the road conditions received by the “Ube” branch office of the Yamaguchi Prefectural Government in 2005 to 2007, along with the percentages of different types of complaints. As shown, on average, about 500 complaints (an average of two complaints per day) were received every year. The complaints concerning places that can be identified by using the system (excluding the complaints in the "Others" category) account for about 90 percent of the total, and the personnel who received the phone calls used the system to identify the places in question before conducting site investigations. Improvements desired by the users included higher resolution of still images, higher shooting angles, seminars on data update methods, and linking with bridge registers and signage registers. There is another area in which an improvement can be made. Although the system enables users to view the present state of problem areas, it is necessary to have some kind of quantitative indices for the assessment of road conditions.

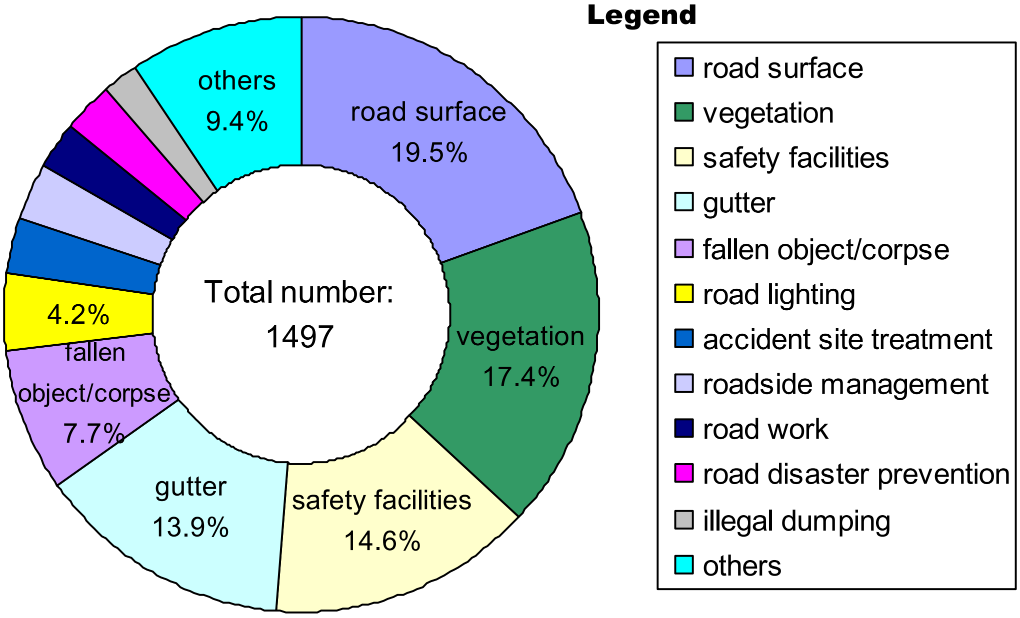

Figure 15. *Breakdown of complaints about road conditions in the district managed by Ube branch office of the Yamaguchi Prefectural Government (from 2005 to 2007).*

5.4 Possible applications in the coming years

Price reductions in the area of video equipment in recent years and high-resolution video images provided by high-definition video recording have made possible the assessment of the state of a remote site by two or more users. Possible applications of the road condition assessment system include not only the use of video data for the management of the maintenance of road facilities but also support for building certification and support for crisis management in times of wild weather. As data are accumulated in the system, it will be possible to assist in road planning in the areas listed below so that the quality of plans can be enhanced:

1) By identifying data patterns, vehicle movement and sight distances at different radii of curvature can be estimated.

2) Examples of successful construction projects including details such as the alignments, slope configuration and appurtenances of in-service roads can be looked up.

3) In the event of road damage caused by a disaster, video images of the pre-disaster conditions provide invaluable information.

6. Conclusions

In this study, a Remote Collaborative Visual Inspection System which designed mainly to assist in visual inspection conducted as part of road patrol and maintenance activities has been developed. The system has made it possible to assess road conditions from a remote location in order to make maintenance/repair decisions. Because video images taken from a road inspection vehicle are used, not only pavement conditions but also the state of road appurtenances can be observed so that collected information can be shared and evaluated by two or more inspectors. Although further study is needed on database structure and data modeling, this study has shown that digital data made available in connection with the newly developed system can be used extensively in the road management and construction departments.

Video images captured by road maintenance vehicles are advantageous because they make it possible to obtain visual information and repeatable inspection results while reducing detection failures. Decision making, however, can still be influenced by subjective elements. In order to solve this problem, it is necessary to apply image processing methods, combine video data with audio data or develop objective and quantitative indicators used in conjunction with other sensors. Then, the needs for some quantitative and data-driven indices that describe road condition without any ambiguity would be our next challenge to work on.

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KaS-Siltopa – A service contract to cover maintenance and upkeep tasks of 350 bridges during 8 years in South-Eastern Finland

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Abstract

Service contract approach was introduced in Finnish Road Administration some years ago to meet the new challenges of infrastructure management. Different service contract models for upkeep of road pavements, road markings and bridges were innovated in addition to routine road maintenance service contracts. The content of the contract depends of numerous variables, which all should be taken into account. Like all multi-criteria tasks, also the development of service contracts needs iteration, trial and error, before the optimal solution can be found.

With bridges the service contract approach is now in piloting phase, and a third long service contract for bridge maintenance and upkeep, named KaS-Siltopa, was signed in the beginning of 2009. This paper analyses that latest contract, to point out the many challenges that the bridge service contracts bring along. Conclusions from the first experiences indicate that the service contracts can bring benefits, but one must have patience. The change from traditional contracting to service providing is in practice much more challenging that what it seems on paper.

Keywords: bridge management, service contract, service provider, maintenance, upkeep

1. Introduction

In the beginning of new millennium the funding allocated for bridge management was too low for optimal long term bridge condition development in Finland. Nowadays the funding is on a decent level, but lack (or scatter) of other resources is setting challenges. As a means to alleviate the situation Finnish Road Administration (FINNRA) has introduced so-called service contract approach for its infrastructure management.

In service contracts the service provider takes the overall responsibility of the named infrastructure assets for a longer time, e.g. five to ten years. Within certain pre-set limits the service provider can innovate or create new bridge maintenance and upkeep practices or optimize the existing ones, in order to achieve the given requirements in most efficient way. The given requirements can include not only technical details, but also societal and other lifetime engineering viewpoints. After the service contract period is over, the responsibility of the infrastructure assets is returned back to FINNRA. In the contract documents it is specified in which condition the infrastructure assets must be, both during the service contract as well as at the end of the contract. Bonuses and sanctions are normally used to guide the service provider.

"The lack (or scatter) of other resources", mentioned in the beginning of this chapter, needs an explanation, in order to make the statement understandable. During and after the severe recession that hit Finland in 1990's, the operational environment on Finnish infrasector went through some radical changes. Governmental bureaus and agencies were streamlined into more corporate-like and the roles were clarified. The old Finnish National Road Administration was divided in two parts, namely the administration part and the contractor part, and later those two parts were fully separated and now the contractor part is a government-owned limited company. The administration part has been in transition phase since the first division but is still a governmental agency, with "provision of smooth, safe and environmentally friendly road connections" being its mission.

At the same time the production practice renewed (all over the world, with Finland being no exception) and nowadays there is no contractors in Finland who have all the expertise and machinery in-house, but the major contracts are split into smaller pieces and for each piece a subcontractor is selected. Logically, to handle that entire contract and subcontract jungle, more and more paper work is needed, and together with the fact that the officials of Finnish Road Administration are getting fewer and fewer, the equation does not converge. As one possible solution to overcome this problem, service contract approach was innovated at Finnish Road Administration. First it was tested in winter road maintenance and the results were so promising that also for other areas of road infrastructure asset management service contracts are now being developed.

Today all routine road maintenance (including winter maintenance) in Finland is handled with service contracts, and the approach is spreading to the maintenance of lighting, pumps and other "road accessories". From the routine road maintenance there is only a small step – on ideological level – to the upkeep of road infrastructure assets, and consequently service contract model visionaries turned their eyes towards road pavements, road markings and bridges. The development of upkeep service contracts started in 2005 and after the first boost there is now a calmer phase going on, as the pilot projects are being followed-up. No new upkeep service contracts are planned to start before more experience and feedback has been received from the ongoing pilot projects. Nevertheless, the vision of Finnish Road Administration still remains: in year 2015 the upkeep service contracts should be in wide use in road infrastructure asset management.

2. Short history of bridge service contracts

The first service contract for upkeep of bridges was developed and the call for bids published in 2005 in Oulu Road Region. It appeared that the service contract model with wider responsibility was not familiar enough for contractors and consequently quite big risk margins were incorporated in the offers. As a result, Road Administration rejected all offers as too expensive. After this first trial FINNRA increased communication and discussion with the contractors in order to clarify the service model approach and to eliminate suspicions. That obviously helped since next year FINNRA renewed the call with only slightly moderated service contract model, and this time better offers were received. Skanska Infra Oy won the 5-year-long contract with WSP Finland Oy as their consultant, and they will take care of the upkeep of more than 670 bridges in southern part of Oulu Road Region until January 2012.

Instead of piloting a different kind of service contract model, Oulu Road Region launched another service contract, only one year after the previous one, this time for the upkeep of 660 bridges during 7 years in northern part of the Region. The applied service model was almost a copy of the first one, and also the winning consortium (Skanska Infra Oy with WSP Finland Oy) was the same as in the first contract.

The main upkeep tasks that the service provider has to carry out in both Oulu contracts include:

- bridge inspections
  - yearly inspections (yearly inspections of bridges are actually part of maintenance process, not upkeep process, but nevertheless included in Oulu bridge upkeep service contract)
  - general inspections
  - special inspections
- supervision of routine road maintenance activities that are directed at bridges
- updating the Bridge Register data on the part of the service contract bridges
- application and development of new techniques or innovations
  - digital pictures in documentation and reporting
  - laser scanning
  - ground penetrating / bridge radar
  - project information portal in documentation and reporting

- programming of the upkeep actions for the bridges
- design of the upkeep actions (e.g. repair designs, demolition designs)
- implementation of the upkeep actions
- design and implementation of traffic arrangements during the upkeep actions
- demolition of bridges
- assistance of authorities (police, rescue authorities, army, etc.) in bridge-related issues
- communication with FINNRA

After the two service contracts in Oulu Road Region only one bridge upkeep service contract was launched before KaS-Siltopa, this time in Turku Road Region. The model used in Turku is simpler, smaller and shorter than the previous two, and the upkeep tasks are carried out in intense cooperation with FINNRA. The contract has an option for two extra years, and both FINNRA and the contractor have agreed to use that option. This model used in Turku Road Region is in some contexts considered more like an extension or update of traditional practice rather than a service contract.

3. Creation of KaS-Siltopa

In the following sub-chapters the KaS-Siltopa service contract will be sliced and analyzed in the same chronological order as it was formed little by little in reality. The most important observations inherent to each slice are highlighted to make the complexity and challengefulness of service contracts more understandable.

3.1 Starting point

The origin of KaS-Siltopa lies in year 2007, when the first bridge upkeep service contract in Oulu Road Region had just started and the next one was under final check. FINNRA Head Office was asking Road Regions whether they would like to pilot new service contracts. In the spring of the same year Ramboll Finland Oy (later Ramboll) had signed a 3-year-long framework contract with South-Eastern Finland Road Region, concerning "development tasks and small bridge designs". Given that framework contract and the positive pioneering attitude of the Road Region towards the bridge service contracts, quite soon it was decided that Ramboll would innovate and prepare the next bridge service contract for the South-Eastern Finland Road Region. At that time only some tentative ideas of the possible content of the contract were drafted at South-Eastern Finland Road Region, but from the beginning it was clear that many principles and details of the new contract would differ notably from the Oulu predecessors.

3.2 Stakeholders of the service contract

In general, there are three parties involved in all construction projects, namely the client, the contractor and the end user. In addition, the project is carried out in some location with certain environmental values, and if the project is carried out properly, legislation is respected and best practices applied. Thus the stakeholder list is longer than the number of signatories indicates.

In principle the service contracts do not differ from that division, but during the formulation of the contract all the viewpoints of the different stakeholders must be considered carefully. As there are only two parties signing the contract, it must be clearly defined in the contract documents, how the environmental values, road users, private land owners, lifetime engineering issues, and other "collateral" issues are taken into account in addition to the simple maintenance, repair and rehabilitation (MR&R) tasks. How to involve all these issues in the contract in so unambiguous a way that both signatories understand their responsibilities and that the documents are not too laborious for either party? The task is not easy to solve in practice.

In KaS-Siltopa all the stakeholders will be represented by two parties, namely the service provider and the client. The service provider consists of the main contractor, subcontractors, bridge upkeep action designers, special inspectors, etc. The client consists of the South-Eastern Finland Road Region with Ramboll as its consultant. Some other experts (e.g. construction information management provider) belong also to the client camp.

While the service provider is mostly concerned in carrying out the technical MR&R actions on the bridges and making profit, the client has more societal motive. The division is not fully black and white, for example it can be useful for the service provider to keep road users satisfied and not disturb them unnecessarily while carrying out the bridge upkeep actions, even if it was not stated in the contract. Also the environmental reputation is today more and more important for all companies; a service provider makes no exception. Likewise, FINNRA has to act responsibly and according to its mission not only on societal or environmental but also on economic level.

In the "old times" the stakeholder division was simpler: FINNRA represented all the lifetime engineering viewpoints, economic, societal, cultural values. The contracts composed by FINNRA dictated in detail for each bridge how to execute the upkeep actions and the contractor carried out those actions, but that is not possible in service contract approach. As mentioned earlier, with signing of the service contract, the overall responsibility of the bridges is passed from the client to service provider, and thus the bridges to which upkeep actions are going to be programmed and designed are not yet known. It is up to service provider to decide how the lifetime engineering viewpoints mentioned in the service contract are taken into account in practice.

Today most lifetime engineering requirements in bridge upkeep practice are still expressed in technical terms instead of performance-based requirements, since this has been found the best way to guarantee the quality of the upkeep works. However, if the bridge industry is going to keep up with the development of other sectors of modern society, it is expected that in the future the performance-based approach will overtake the regulation-based approach also in bridge MR&R. Thus more space must be left for the service provider's innovations, although at the time of the signing of the contract the service provider itself would not see this as a crucial issue.

Figure 1 shows the stakeholder viewpoints in overall road maintenance as described in the procurement strategy of FINNRA. The service contracts should be composed so that the wanted state (on the right hand side of the triangle) would be reached in most effective way. This means that the responsibilities must be re-divided and that all parties have to understand and find their new roles in the altered operational environment. It means also that the requirements in the contract documents can be expressed by using performance-based criteria. The understanding (and accepting) of the new operational environment and adoption of performance-based approach in requirement setting are the biggest challenges in the wider implementation of service contracts. Hopefully in the future service contracts more and more items and requirements can be expressed by using performance-based approach.

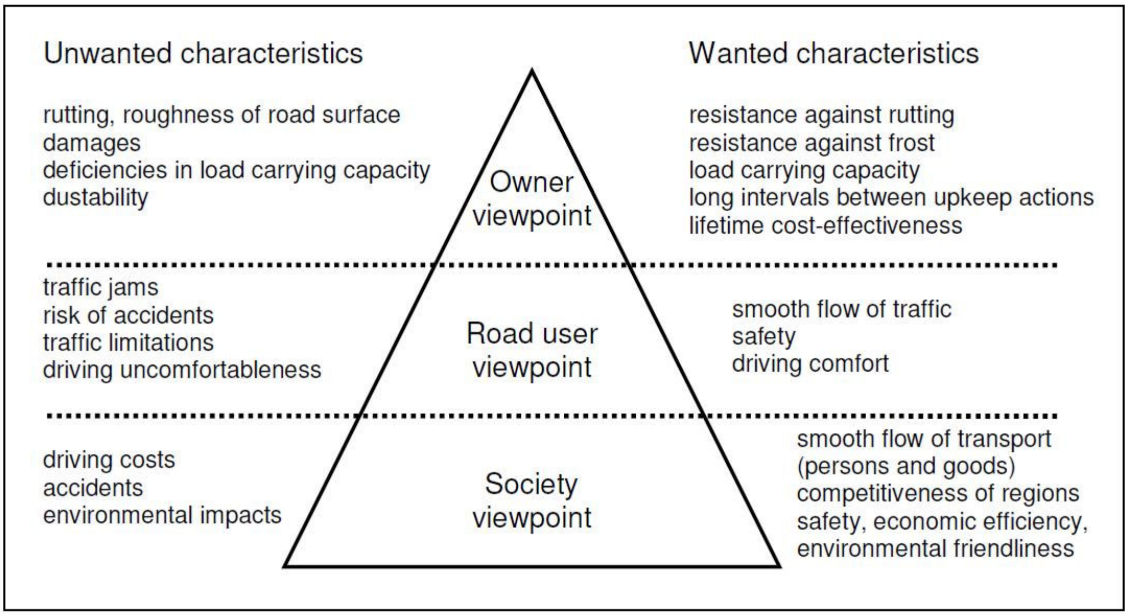

Figure 1. *Different stakeholder viewpoints concerning road maintenance, expressed with performance-based criteria [1].*

3.3 Client expectations and objectives

As described in chapter 3.1 the formulation of the client line-up was very easy. The Road Region had framework contracts with other bridge consultancies too, but basically based on Ramboll's references and personnel, Ramboll was chosen to innovate and prepare the bridge service contract together with the Road Region. Ramboll had no previous experience in preparing bridge service contracts, but Ramboll's knowledge and experience in bridge upkeep business (action and repair plans, general and special inspections, strengthening, etc.) is solid and deep. With this service contract Ramboll was looking for widening its repertoire and getting more deeply involved in the service contract strategies of FINNRA, and deepening thus the cooperation with one of its most important customers, while offering its bridge upkeep expertise to Road Region.

The expectations of the South-Eastern Finland Road Region were various, including wider strategic visions but also practical issues. These Road Region expectations also formulated the main objectives of the KaS-Siltopa service contract.

On general level Road Region was hoping that with the new bridge service contract the Region could:

- get rid of the so-called "routine maintenance lag" on the part of the service contract bridges
- test the practice where the yearly inspections and routine maintenance is carried out by bridge specialists (and not by road maintenance service contracts like is done nowadays)
- reduce the work load of the Road Region by transferring majority of the everyday bridge routines to the service provider
- enhance the introduction and application of risk management and lifetime engineering principles, as well as overall responsibility approach in bridge MR&R practice
- contribute to FINNRA Head Office's strategic endeavor by piloting a different bridge service contract

3.4 Main features of the contract

In creation of KaS-Siltopa the contents of Oulu bridge upkeep service contracts were already known. Feedback about Oulu service contracts had been received from the contractors and the Oulu Road Region personnel. Like expected, in many issues there was difference in opinions depending whether a contractor was asked or whether a Road Region representative was interviewed. Everybody understood those Oulu contracts as a first step in the piloting phase of bridge upkeep service contracts, so minor flaws or lapses of the contract documents were not highlighted. Instead, the service contract proceeding in its totality was under review.

In addition to Oulu service contract analyses, feedback and source data was also received via direct communication with the contractors in a two-day-long workshop that was organized to inform the contractors about the upcoming service contract in South-Eastern Finland and to get their opinion about the main features of both the KaS-Siltopa content and the tender process. The tender process was a subject of discussion because the contract documents in the service contract approach tend to be much more cumbersome to go through than traditional contract documents.

The feedback was analyzed and the direction and main features of the service contract finally decided during the discussions between Ramboll and South-Eastern Finland Road Region. During spring and summer 2008 it was decided that KaS-Siltopa would:

- be advertised effectively to the contractors before the tender process (that process had started already in winter)
- have a long tender process in the "quiet" time of the year
- have such a content and easy tender documents that also smaller companies could take part in the tender process and strive for becoming the service provider
- be much smaller than its Oulu predecessors, containing only about 350 bridges on two road maintenance regions
- include also the routine maintenance of bridges (yearly inspections, yearly and continuous bridge maintenance works) in addition to bridge upkeep tasks
- have a duration of almost 8 years for upkeep actions and 7 years for routine maintenance actions
- have the so-called damage points and condition class of the bridges as the main criteria for the follow-up of the contract
- not include the general inspections of the bridges
- have a carefully thought balance between risks and responsibilities

There were lots of challenges in deciding the direction and the main features of KaS-Siltopa. It was well understood that the main features would form the skeleton of the contract, thus either seducing or scaring the tenderers. Before the main features could be nailed down some fundamental questions had to be considered carefully:

- How big is the yearly funding going to be now and during the next eight years (and can that funding be guaranteed)?
- How will the infrasector business, repair methods, requirements, norms or standards change during the duration of the service contract (and how to prepare for those changes)?
- What criteria should be used to evaluate the fulfillment of the contract and what numbers can be set on those criteria (ambitious enough but not too strict to scare the tenderers)?

- How extensive should the tender and contract documents be (could the documents be made simpler than what they were in Oulu)?
- What kind of contractors are wanted to take part in the tender process (size, turnover, expertise, number of own workers, etc.)?
- What kind of service contract model should be chosen (a partnership model, area model, a hybrid, or some other)?
- What other service contracts are under development in the South-Eastern Finland Road Region (how should they interact or coincide with the bridge service contract)?
- On which area the service contract should be applied (in which part of the Road Region the development of the bridge condition, traffic or other boundary conditions are most appropriate for the purpose)?

These fundamental questions were very difficult to answer, since each of them included many uncertainties and no objective data was available to solve them. Some of the questions were of delicate nature and not necessarily suitable for wider discussion before the tender process. Thus the best solution to find answers to those questions was to rely on expert opinions and discussions between Ramboll and Road Region.

It was seen immediately that there would be no single correct answer to any of the fundamental questions, but the process would be more likely a constant optimization procedure, a multi-criteria decision-making process, which needed open mind but also a lot of determination. In spite of the opportunity, real multi-criteria decision-making methods with iteration rounds were not used in deciding the main issues of the KaS-Siltopa. This was seen too complicated, given the available time and the variety of options to choose from. Also the techniques were not familiar to all involved persons. Instead of standardized multi-criteria decision-making methods, "instinct" was used. Long experience, "silent information" from different sources and cause-consequence understanding were combined instinctively to find the solutions to the fundamental questions and thus set the direction of KaS-Siltopa.

The decision-making concerning the direction and main features of the service contract extended from the original plan, which led to the situation where detailed planning of some parts of the contract overlapped time-wise with decision-making about the main features of some other parts. This required very careful record of the versions and decisions, but in spite of all efforts some repetition of work occurred. However, this was anticipated, since during the spring 2008 FINNRA had published a study [2] of the existing upkeep service contracts, and in that study it had been found that all upkeep service contracts had faced minor or bigger problems in the creation phase.

Finally, during summer 2008 the last guiding decisions had been made, and all effort could be turned towards the detailed preparation of the contract and tender documents. The detailed contract documents guide the service provider during the 8-year-long duration of the service contract. The main tasks of the service provider in KaS-Siltopa are following:

- Routine maintenance of the bridges (1st of Oct. 2009 – 30th of Sept. 2016)
    - yearly and continuous maintenance actions on bridges
    - yearly inspections of bridges
    - removal of the "routine maintenance lag" (that had been accumulating during past years or even decades)
- Upkeep of the bridges (1st of Jan. 2009 – 30th of Sept. 2016)
    - programming of the upkeep actions for the bridges (e.g. separate small repairs, full renovation or widening of a bridge, replacement of a small bridge with culvert, renewal of a culvert)
    - special inspections of the bridges
    - design of the upkeep actions (e.g. repair designs, demolition designs)
    - implementation of the upkeep actions
    - updating the Bridge Register data on the part of the service contract bridges
- design and implementation of traffic arrangements during the maintenance or upkeep actions
- assistance of authorities (police, rescue authorities, army, etc.) in bridge-related issues
- communication with FINNRA and also with other contractors or service providers that produce services (road pavements, road markings, automatic speed control, etc.) to FINNRA in same area

At first glance the final content of KaS-Siltopa does not differ much from the Oulu service contracts, but in some basic questions (e.g. how damage points are used for evaluation of the fulfillment of the contract), as well as in many details the contracts have considerable differences. The biggest differences can be found in contract documents that address sanctions and bonuses, unit price lists (in tender process), risk management, implementation of new techniques, provisions for changes during the contract, reporting and the division of responsibilities between different service providers on the same area.

By trying many new features while keeping some basic structures unchanged it was estimated that KaS-Siltopa would best fulfill its role as a pilot project. In few years time the first deeper comparison analyses between Oulu and KaS-Siltopa service contracts can be made. By then maybe some new bridge service contract pilots are under way as more feedback is received all the time from the existing upkeep service contracts.

3.5 Preparation of the content and tender documents of KaS-Siltopa

In theory the detailed content creation and tender document preparation should have started after the decisions about the main features of the contract, but in practice it was going on parallel with the extended decision-making process. In the detailed planning phase the questions did not end, on the contrary, but most of them were of technical nature and could thus be solved easily by using Ramboll experience and expertise.

However, a new interesting challenge came up in the document preparation phase. The templates that had been used at Road Administration for creating tender and contract documents for traditional projects, did not fit to the service contract. Those templates had been created to ease paper work at Road Administration, and for standard projects they had been working well. Normally the contract documents were divided in commercial and technical documents, and especially the commercial documents were almost standardized at Road Administration. Now, with KaS-Siltopa, considerable changes had to be made to the document templates, both commercial and technical. This required communication not only with the bridge people but also the lawyers of Road Administration, since the changes to the familiar contract texts might have juridical consequences.

The mismatch between the existing templates and the documents that were required in service contracts had been noticed already in Oulu pilots. Even more severe than the incompatibility with Road Administration templates, was the fact that the service contract approach did not fully cooperate with the terms written in the "base" document of Finnish construction sector, namely YSE 1998, the General conditions for building contracts. In practice all construction contracts in Finland refer to YSE 1998, thus it could not be overlooked. The solution in creation of the contract documents of KaS-Siltopa was that in those points where reference was made to YSE 1998, a statement was added indicating how the in that particular case should be proceeded. These points included responsibilities, obligations, guarantees, etc. Of course stating exceptions in familiar contract templates resulted in contract documents where the juridical ground was firm but the legibility suffered. However, that could not be avoided. Hopefully with the future service contracts also this problem can be solved.

Another challenge was the number of service contract documents. One of the main issues that had been decided, was that the tender (and contract) documents should not be too laborious to write or read. Either option would increase the costs of the Road Region, the former in form of pay to Ramboll, the latter in form of worse or fewer offers from the tenderers. Nevertheless, the comprehensiveness of the service contract required quite detailed guidance for the service provider, so the number of tender documents could not be reduced much from the Oulu predecessors. Unlike in traditional Road Administration contracts, the division between technical and commercial documents was not razor-sharp in KaS-Siltopa. Stricter division between technical and commercial documents would have required increase in number of separate contract documents but that was not the wanted solution.

Finally, the following KaS-Siltopa-specific tender documents were prepared for the tender process:

- Letter of invitation for tenders
- Draft of the service contract
- Contract-specific terms (with four annexes)
- Basics of programming upkeep actions
- Tender forms
- Tender process phase I, evaluation table
- Sanctions and bonuses
- Service contract specific product requirements
- Condition objectives for the contract area bridges
- Quality verification and reporting in the service contract
- Content of the action and quality plan
- Product cards for bridge maintenance and upkeep
- Instructions and quality requirements for yearly inspections
- Yearly inspection form
- Bridge lists and location maps (a separate GIS-based Internet service)
- Division of responsibilities

3.6 Selection of the service provider

After the tender documents had been delivered via Internet-based project information service portal to those contractors who had sent their expression of interest to South-Eastern Finland Road Region, the procedure for selecting the service provider became more traditional.

The tenderers had two and a half months time to make the offer. Making the offer included following tasks:

- building up a service provider team (contractor, design consultant, subcontractors, etc.)

- going through over 200 pages of technical and commercial tender documents specific just for this service contract
- being familiar with all general and detailed directives and specifications that the Finnish Road Administration and Finnish Rail Administration have issued concerning bridge upkeep and maintenance
- getting familiar with the 350 bridges presented in detail on the GIS-based Internet service
- having bilateral discussions with Road Region
- writing the action and quality plan for the fulfillment of the contract
- inserting the unit prices into the tender forms
- posting the offer to South-Eastern Finland Road Region.

A noteworthy detail in the tender process was that the most proficient service provider was sought after, not the cheapest. The quality plans composed by the tenderers were ranked and quality points given according to preset criteria, and using a certain equation those quality points were converted into a reduction factor, by which the tender price was multiplied and thus a comparison price was obtained. The tenderer of the lowest comparison price offer would become the service provider for KaS-Siltopa.

By the deadline 10th of November 2008, three offers were received at South-Eastern Finland Road Region. One of the offers had to be rejected due to too low quality, but the two remaining ones were almost equal in terms of quality. As the other offer was about 11 % cheaper than the other one, and because the quality-based reduction factor was almost the same for both accepted offers, the cheaper offer had also the lower comparison price.

Before signing the service contract, a contract inspection was held between the winning tenderer and the client to make sure that both parties had understood the content, responsibilities and obligations of the contract in the same way. As no surprises came up in the contract inspection, there were no barriers for signing of the service contract.

Finally on 14th of January 2009 KaS-Siltopa bridge maintenance and upkeep service contract was signed between Kesälahden Maansiirto Oy and South-Eastern Finland Road Region. From the first ideas of introducing a bridge service contract in South-Eastern Finland Road Region to the signing of that contract, approximately 18 months had passed. The actions on the KaS-Siltopa bridges started in April 2009 after the snow had melted but the repair design started soon after signing of the service contract.

4. Conclusions

The Finnish Road Administration (FINNRA) has stated in its strategy that in year 2015 upkeep service contracts are in wide use. In year 2008 the Board of FINNRA decided that no new service contracts will be started but the existing ones will be followed-up and feedback gathered, for now. That seemed to be a wise decision because the rhythm to launch new upkeep service contracts was too fast for the infrasector, and also feedback from the existing contracts to guide the development of the next ones was still very scarce. Also during the last few years the infrasector in Finland had overheated and the contractors had hands full of work. It was not clear whether there would be enough interest towards service contracts which are more laborious for contractors than the traditional contracts.

Time-out was needed also because truth is that construction sector, with infrasector in front, is very slow in digesting new changes. The service contract approach is much bigger change than what it seems at first glance. The whole network of contractors, subcontractors, material suppliers and consultants need time to get familiar with this new approach in upkeep of infrastructure.

Time and toil is also needed in making space for service contracts in the contract templates and General conditions for building contracts. At the moment the usability of those templates or general conditions in composing service contracts is questionable, but the infrasector is so used to those templates and documents that they cannot be overlooked either. This results in problems in the service contract creation phase. Who will take the effort to develop a new, flexible "service contract template" on infrasector?

Finally, determination and true commitment is needed from all involved persons and parties, in order to get the 18-month-long creation phase shorter and more fluent.

In spite of apparent challenges the maintenance and upkeep service contracts are a logical and reasonable step in improving the productivity of infrasector and bettering the ranking of infrasector on the innovation scale. But one must accept also the fact that the changes take time. Especially during economic boom the reluctance to learn new things instead of gathering maximum profits grows. However, it is expected that the global recession will soon hit the Finnish infrasector too, so maybe the ground will be more fertile for new maintenance and upkeep service contract pilots.

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developed for concrete structures it is basically generic and can be adopted to any structures and materials [1], [2].

The LIFECON concepts can be expressed by the following characteristics of the system:

- predictive,
- integrative,
- probabilistic and
- optimizing

A predictive system is able to predict the degradation of structures and to plan the maintenance, repair and rehabilitation (MR&R) actions over a long period of time. An integrative system is able to evaluate degradation, costs, environmental impacts, risks and other important indicators of lifetime quality. In a probabilistic system the degradation of structures is predicted with stochastic methods which allow the use of reliability theory in timing of MR&R actions. Using such a life cycle management tool it is possible to optimize the maintenance strategy and to conduct systemized policy.

2. Methods

2.1 Modules and Databases

The structures whether bridges, roads, buildings or nuclear power plants are divided into smaller structural parts which can be treated as homogenous with respect to materials, structural features and environmental stresses. These structural parts are called “modules” and they serve as basic structural units in the analysis and planning processes of the system. The databases which serve as initial data sources in the calculation processes are consistent with the modular breakdown of structures. The modular database consists of identification data, history data, structural data, material data, measuring data, exposure data, observed damage data (inspection data) and specification data for the future maintenance and repair actions. Another database consisting of data on costs, environmental impacts, degradation rate and service life etc. of MR&R systems is also produced.

2.2 Combined Life Cycle Analysis

The core of the management system consists of a combined condition, cost and environmental impact analysis. The condition analysis is produced automatically based on degradation models and predefined limit states of condition. The condition analysis is stochastic (based on the Markov Chain method) and it is capable of predicting the probability of the structure to be at any of the condition states during the treated design period. The analysis consists also an automatic condition guarding system which is able to trigger MR&R actions whenever the predefined limit state of condition is exceeded.

Transition probability matrix of original structure

State	0	1	2	3	4
0	0.74	0.26	0	0	0
1	0	0.77	0.23	0	0
2	0	0	0.79	0.21	0
3	0	0	0	0.79	0.21
4	0	0	0	0	1

DEGRADATION OF ORIGINAL STRUCTURE

Coefficient c	0.3
Exponent n	0.9

Transition probability matrix of repair

State	0	1	2	3	4
0	1	0	0	0	0
1	0.95	0.05	0	0	0
2	0.92	0.05	0.03	0	0
3	0.9	0.05	0.03	0.02	0
4	0.88	0.05	0.03	0.02	0.02

REPAIR DATA

Cost	100	Euro/m^2
Non-Ren Ene	100	MJ/m2
CO_2	10	kg/m2

Transition probability matrix of degradation after repair

State	0	1	2	3	4
0	0.85	0.15	0	0	0
1	0	0.81	0.19	0	0
2	0	0	0.80	0.20	0
3	0	0	0	0.78	0.22
4	0	0	0	0	1

DEGRADATION AFTER REPAIR

Coefficient c	0.1
Exponent n	1.2

REPAIR CRITERIA

Limit state	3
Max Prob	0.5

GENERAL DATA

Design period	40	Years
Discount rate	3	%
Surface area	50	m^2

RESULTS

LC COSTS PER UNIT AREA

Cumulative real costs	200	Euro/m^2
Cumulative PV costs	111	Euro/m^2
Average annual costs	5.00	Euro/m^2/yr
Equalised annual costs	4.64	Euro/m^2/yr
Non-Ren Energy	200	MJ/m2
CO_2	20	kg/m2

TOTAL LC COSTS

Cumulative real costs	10000	Euro
Cumulative PV costs	5526	Euro
Average annual costs	250	Euro/year
Equalised annual costs	232	Euro/year
Non-Ren Energy	10000	MJ
CO_2	1000	kg

State Year	0 Prob(0)	1 Prob(1)	2 Prob(2)	3 Prob(3)	4 Prob(4)	Average D	Prob (>3)	Repair criteria	Number of repairs	LC costs real	Discount factor	LC costs discounted	Non-Ren Energy	CO_2
0	1.000	0.000	0.000	0.000	0.000	0.00	0.000	0	0	0	1.000	0	0	0
1	0.738	0.262	0.000	0.000	0.000	0.26	0.000	0	0	0	0.971	0	0	0
2	0.544	0.397	0.059	0.000	0.000	0.52	0.000	0	0	0	0.943	0	0	0
3	0.401	0.450	0.136	0.013	0.000	0.76	0.013	0	0	0	0.915	0	0	0
4	0.296	0.453	0.209	0.039	0.003	1.00	0.042	0	0	0	0.888	0	0	0
5	0.218	0.428	0.267	0.076	0.011	1.23	0.086	0	0	0	0.863	0	0	0
6	0.161	0.389	0.307	0.117	0.026	1.46	0.143	0	0	0	0.837	0	0	0
7	0.119	0.343	0.329	0.159	0.050	1.68	0.209	0	0	0	0.813	0	0	0
8	0.088	0.297	0.337	0.196	0.083	1.89	0.279	0	0	0	0.789	0	0	0
9	0.065	0.253	0.332	0.228	0.123	2.09	0.351	0	0	0	0.766	0	0	0
10	0.048	0.212	0.318	0.252	0.170	2.28	0.422	0	0	0	0.744	0	0	0
11	0.035	0.177	0.298	0.268	0.222	2.46	0.490	0	0	0	0.722	0	0	0
12	0.026	0.146	0.275	0.277	0.277	2.63	0.553	1	0	0	0.701	0	0	0
13	0.910	0.049	0.025	0.011	0.006	0.15	0.017	0	1	100	0.681	68	100	10
14	0.776	0.173	0.029	0.014	0.008	0.30	0.022	0	1	100	0.661	68	100	10
15	0.662	0.255	0.055	0.017	0.011	0.46	0.028	0	1	100	0.642	68	100	10
16	0.565	0.304	0.092	0.024	0.015	0.62	0.039	0	1	100	0.623	68	100	10
17	0.482	0.330	0.130	0.038	0.020	0.78	0.058	0	1	100	0.605	68	100	10
18	0.411	0.339	0.165	0.056	0.028	0.95	0.084	0	1	100	0.587	68	100	10
19	0.351	0.336	0.195	0.078	0.040	1.12	0.118	0	1	100	0.570	68	100	10
20	0.299	0.324	0.218	0.101	0.057	1.29	0.158	0	1	100	0.554	68	100	10
21	0.256	0.307	0.234	0.124	0.079	1.46	0.203	0	1	100	0.538	68	100	10
22	0.218	0.287	0.244	0.145	0.106	1.63	0.251	0	1	100	0.522	68	100	10
23	0.186	0.265	0.248	0.164	0.137	1.80	0.301	0	1	100	0.507	68	100	10
24	0.159	0.243	0.247	0.179	0.173	1.96	0.352	0	1	100	0.492	68	100	10
25	0.135	0.220	0.242	0.191	0.212	2.12	0.402	0	1	100	0.478	68	100	10
26	0.116	0.199	0.234	0.199	0.253	2.28	0.452	0	1	100	0.464	68	100	10
27	0.099	0.179	0.223	0.204	0.296	2.42	0.500	0	1	100	0.450	68	100	10
28	0.084	0.159	0.211	0.205	0.340	2.56	0.546	1	1	100	0.437	68	100	10
29	0.914	0.046	0.023	0.011	0.007	0.15	0.018	0	2	200	0.424	111	200	20
30	0.780	0.171	0.027	0.013	0.009	0.30	0.022	0	2	200	0.412	111	200	20
31	0.665	0.254	0.053	0.016	0.012	0.46	0.028	0	2	200	0.400	111	200	20
32	0.568	0.304	0.090	0.023	0.015	0.62	0.039	0	2	200	0.388	111	200	20
33	0.484	0.330	0.129	0.037	0.021	0.78	0.057	0	2	200	0.377	111	200	20
34	0.413	0.339	0.164	0.055	0.028	0.95	0.084	0	2	200	0.366	111	200	20
35	0.353	0.336	0.194	0.077	0.040	1.12	0.117	0	2	200	0.355	111	200	20
36	0.301	0.325	0.217	0.100	0.057	1.29	0.157	0	2	200	0.345	111	200	20
37	0.257	0.308	0.234	0.123	0.079	1.46	0.202	0	2	200	0.335	111	200	20
38	0.219	0.288	0.244	0.144	0.105	1.63	0.249	0	2	200	0.325	111	200	20
39	0.187	0.266	0.248	0.163	0.137	1.80	0.299	0	2	200	0.316	111	200	20
40	0.159	0.243	0.247	0.178	0.172	1.96	0.350	0	2	200	0.307	111	200	20
41	0.136	0.221	0.242	0.190	0.211	2.12	0.401	0	2	200	0.298	111	200	20
42	0.116	0.200	0.234	0.199	0.252	2.27	0.450	0	2	200	0.289	111	200	20
43	0.099	0.179	0.223	0.203	0.295	2.42	0.498	0	2	200	0.281	111	200	20
44	0.084	0.160	0.211	0.205	0.339	2.55	0.544	1	2	200	0.272	111	200	20
45	0.914	0.046	0.023	0.011	0.007	0.15	0.018	0	3	300	0.264	137	300	30

Figure 1. Combined Life Cycle Analysis.

In Figure 1 a scheme of the combined analysis table is presented. Left the Markov Chain based condition analysis with transition probability matrixes, right the cost calculators for determination of the life cycle costs and the environmental impacts from the MR&R actions are presented.

2.3 Condition analysis

Many kinds of degradation models have been used in the LCM Tools. Usually the degradation of a structure is expressed by a power function of time. Both the coefficient a and the exponent n are functions of material, structural and environmental parameters.

$$f = a \cdot t^n \qquad (1)$$

where
f is degradation function
a coefficient (function of material, structural and environmental parameters), and
n exponent of time (function of material and environmental parameters).

The degradation function f expresses the relative degradation with the value 0 at the beginning of service life and 1 at the end of service life. Considering a discrete degradation ranking system N[0, 1, 2,...,N_{ls}, N_{ls+1},…N_{max}], where state N = 0 corresponds to the degradation value f = 0 and state N_{ls} (limit state) corresponds to value f = 1 we can write as follows [2]:

$$N = c \cdot t^n \qquad (2)$$

where
c is coefficient, and
n exponent of time.

The relationship between the coefficients c and a is the following:

$$c = N_{ls} \cdot a \qquad (3)$$

where N_{LS} is the limit state ($0 < N_{ls} < N_{max}$).

In a Markov Chain process discrete condition states N[0, 1, 2,...,N_{ls}, N_{ls+1},…N_{max}] are used instead of continuous condition function. The condition at any year is expressed by a vector representing the probabilities of a structure to be at any of the defined condition states during a certain year. A condition state vector, W, looks in a 5 state system like that presented in Equation 4. As the module must be at any one of the condition states the sum of probabilities must be 1.

$$W(t) = [w_0, w_1, w_2, w_3, w_4] \qquad (4)$$

where each w_i is the probability of the module to be at state i in a year (i = 0, 1, 2, 3, 4).

The annual changes in a condition state vector are predicted by transition probability matrices. There are two kinds of transition probability matrices: (1) matrices for degradation and (2) matrices for MR&R action effects. To predict the effect of annual degradation on the condition of a module the matrices for degradation are used. The matrices for action effects are used only for those years when MR&R actions are performed.

In a 5-state system the assumed transition probability matrix would look like that in Figure 2. The elements in the matrix express the probability of a module to transit from the prevailing condition state (vertical axes) to any other condition state (horizontal axes) within a year. In the case of degradation we usually have an assumption that the modules either remain at the same state or drop to the next one within a year. In that case the "remain-in-state" probabilities can be determined by subtracting the "drop-to-next-state" probabilities from 1. Since there is no higher condition state than 4, modules attained that condition state cannot transit to any other condition state. Thus the transition probability, p_{44}, is always 1.

State	0	1	2	3	4
0	$1-p_{01}$	p_{01}	0	0	0
1	0	$1-p_{12}$	p_{12}	0	0
2	0	0	$1-p_{23}$	p_{23}	0
3	0	0	0	$1-p_{34}$	p_{34}
4	0	0	0	0	1

Figure 2. Transition probability matrix for degradation.

In case Equations 2 and 3 are valid an approximation for the transition probabilities (p_{01}, p_{12}, p_{23} and p_{34}) can be determined as follows:

$$p_{i;i+1} = \frac{1}{\left(\frac{i+1}{c}\right)^{\frac{1}{n}} - \left(\frac{i}{c}\right)^{\frac{1}{n}}} \tag{5}$$

where i is any state from 0 to 3.

The appearance of an action effect matrix is as presented in Figure 3.

State	0	1	2	3	4
0	p_{00}	0	0	0	0
1	p_{10}	p_{11}	0	0	0
2	p_{20}	p_{21}	p_{22}	0	0
3	p_{30}	p_{31}	p_{32}	p_{33}	0
4	p_{40}	p_{41}	p_{42}	p_{43}	p_{44}

Figure 3. Transition probability matrix for MR&R action effects.

The action effect matrixes are specific to each MR&R action. As it is assumed that the condition state is always improved by an action or at least the condition state remains the same all probabilities above the diagonal are 0. Other elements may have a value ranging from 0 to 1. The sum of each row of probabilities must be 1. Normally repair actions bring the structures close to the perfect condition so that the elements in the first column of the matrix are close to 1.

In the Markov Chain based condition analysis the annual condition state vectors are solved using Equation 6. The condition state distribution of any year, W(t), is obtained by multiplying the condition state distribution of the previous year by the transition matrix P.

$$W(t) = W(t-1) \times P \qquad (6)$$

By the Markov Chain method a deterministic condition analysis is made stochastic. In a stochastic condition analysis the timing of MR&R actions can be based on the reliability theory. The automatic condition guarding system triggers MR&R actions always when the predefined limit state of condition is exceeded by the maximum allowable probability.

The Markov Chain based condition analysis may consist of several degradation types. Several condition analysis tables are needed according to the number of degradation types. E.g. in the case of concrete structures th following degradation types may be addressed:

- Carbonation and corrosion
- Chloride penetration and corrosion
- Carbonation and corrosion at cracks
- Chloride penetration and corrosion at cracks
- Degradation of concrete
- Degradation of possible protection system.

The condition analysis ranges from the beginning to the end of the design period. For these years condition vectors are determined in a column with respect to every degradation type. The changes in condition as a result of MR&R actions are evaluated by matrices for MR&R action effects. The matrices for degradation after a MR&R action may differ from that before the action.

The degradation rate of a module is retarded by protection measures. The retarding effect of a protective system is defined in the database of protective systems for each degradation type separately. The retarding effect may change with time i.e. with degradation of the protective system itself.

2.4 Determination of Life Cycle Costs and Environmental Impacts

The life cycle costs are counted based on ISO whole life costing principles (ISO 15686). The costs are given as:

- real costs and
- present value costs.

The real costs refer to MR&R costs throughout the treated time without discounting. The total real costs are calculated from the equation:

$$C_R = \sum_{i=0}^{t} \sum_{j=1}^{n_i} C_{j;i} \tag{7}$$

where

C_R is	the sum of real costs from the treated time frame, Euro/m^2,
$C_{j;i}$	costs of the jth maintenance action in year i, Euro/m^2,
n_i	number of maintenance action in year i, and
t	number of years in the time frame (length of the span in years).

Present value costs refer to maintenance costs discounted to the present day by the discount factor. As the discount factor diminishes with time, the PV costs of actions scheduled near to the start of the time frame are greater than those of respective actions scheduled later in the time frame. The present value costs are calculated from the equation:

$$C_{PV} = \sum_{i=0}^{t} \sum_{j=1}^{n_i} C_{j;i} \frac{1}{(1+r)^i} \tag{8}$$

where

C_{PV} is	sum of discounted (present value) costs from the treated time frame, Euro/m^2, and
r	rate of interest.

The unit costs for various MR&R actions are stored in the database of MR&R systems. The total action costs are determined by multiplying the unit costs by the quantity of the MR&R action expressed with the same units as the unit costs.

To compare different maintenance strategies it is advisable to redistribute the sum of LC costs evenly into annual costs. This can be done based either on real costs or PV costs, so two kinds of annual costs are defined:

- average annual costs and
- equalized annual costs.

The average annual costs are defined as the sum of real costs divided by the number of years in the time frame:

$$A_A = \frac{C_R}{t} \tag{9}$$

where
A_A is average annual costs, Euro/m^2/year.

The equalised annual costs are determined by multiplying the sum of discounted costs by the annuity factor:

$$A_E = C_{PV} \cdot \frac{r(1+r)^t}{(1+r)^t - 1} \tag{10}$$

where
A_E is equalised annual costs, Euro/m^2/year.

The equalised annual costs depend on how the maintenance actions are scheduled within the time frame. Maintenance actions scheduled near to the start of the time frame increase the equalised annual costs more than those scheduled later in the time frame. This feature is emphasised with increasing rate of interest.

The environmental impacts from the MR&R actions are calculated in the same way as MR&R costs over the selected time frame (ref. Equation 7). Every environmental parameter is counted separately from all MR&R actions and from all years of the time frame. The action specific environmental impacts per unit are stored in the database of MR&R systems. The discounting method is not used for environmental impacts.

2.5 Special Inspections

Special Inspections form an essential part of a life cycle management system. Special inspections include taking samples from modules and the condition assessment based on those samples. A special data form is reserved for inputting the condition assessment data to the modular database. E.g. in the case of concrete structures the input data may include:

- Special inspection year
- carbonation depth
- depth of critical chloride content
- thickness on concrete cover
- crack width
- amount of cracks.

Based on the special inspection data the degradation models are calibrated specifically for each module. These models are used instead of the original ones in the consequent timing of MR&R actions. When more and more special inspection data is obtained also the general degradation models can be re-evaluated using that data.

3. Process

Figure 4 shows the calculation process and the data flow of a LCM process schematically. On the top the databases of structures, modules and MR&R systems are presented. The databases which in some cases can be connected to some exterior databases form a considereble part of the system.

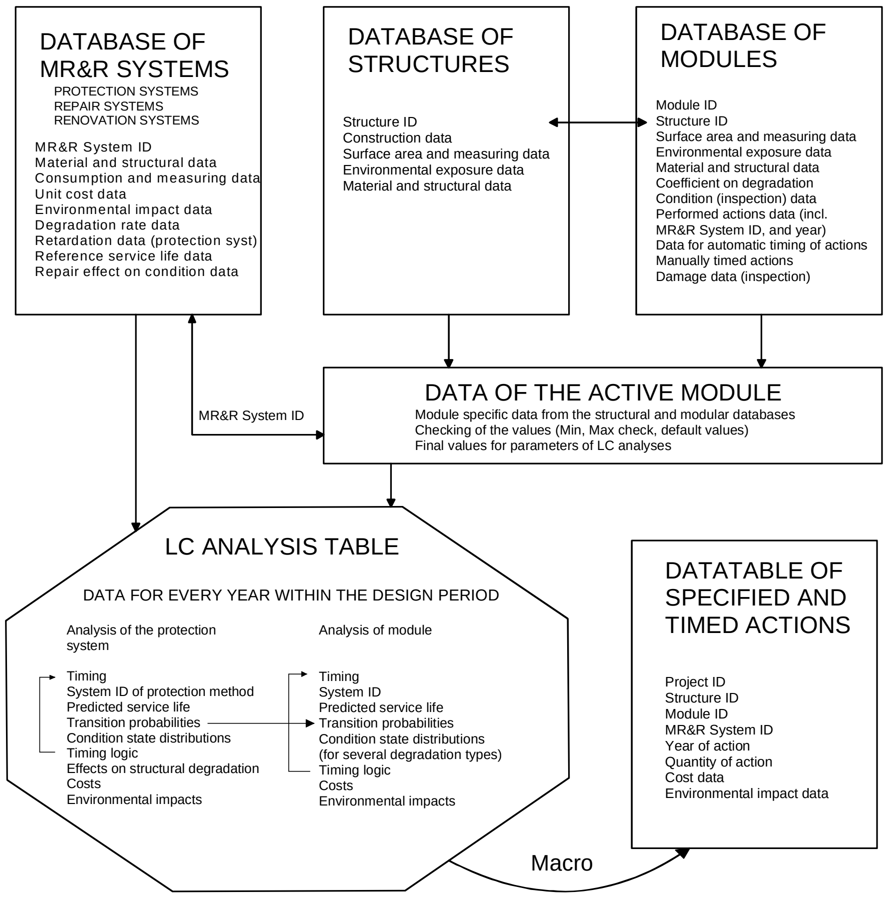

Figure 4. Calculation process of a life cycle management tool.

Only one module in turn is active in the LC analysis processes. The data of the active module is extracted from the databases. The checking of initial data consists of a minimum-maximum check and application of default values in case of missing data. Then the data of the active module are inserted in the LC analysin table.

The LC analyses have been systemised so that the calculation routines are always the same irrespective of the module at hand. Only the initial data change according to the active module. As a result of the LC analyses MR&R actions are defined and timed and the data on action specific cost and environmental impact data are determined. The data on actions are gathered by a special macro program to the data table of specified and timed actions.

The user of the LCM Tool can view the life cycle action profiles specifically to each modules. The data of these profiles contain the year, specification, amount, costs, and environmental impacts of each MR&R action. If the user is not satisfied with this automatically produced action profile he/she can make changes to it manually.

In some of the LCM tools the process goes on to Project Design and Annual Resources Design. These phases call for sorting, filtering and supplementing of data in the datatable of the specified and timed MR&R actions.

4. Conclusions

Several life cycle management tools have been developed in Finland during the years 2002 - 2008. The tools were designed applicable to bridges, roads, building envelopes and nuclear power plants. All these systems were based on the ideas of the European Union Project LIFECON in 2001-2003. These ideas can be expressed by the following characteristics of the system: predictive, integrated, probabilistic and optimizing.

The structures whether bridges, roads, buildings or nuclear power plants are divided into smaller structural parts which can be treated as homogenous with respect to materials, structural features and environmental stresses. These structural parts are called “modules” and they serve as basic structural units in the analysis and planning processes of the system.

The core of the management system consists of a combined condition, cost and environmental impact analysis. The condition analysis is produced automatically based on degradation models and predefined limit states of condition. The condition analysis is based on the Markov Chain method and equipped with a condition guarding system it is capable of triggering MR&R actions whenever the predefined condition limits are exceeded. When the MR&R actions are specified and timed the life cycle costs and the environmental impacts due to MR&R actions are calculated automatically by the side of the condition analysis.

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Effectiveness of infrastructure asset management at public agencies

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Abstract

For many public agencies, maintenance, renovation and reconstruction work (MR&R) represents one of the budgetary items with the largest annual expenditures. In order to spend the resources more effectively, public agencies need to implement infrastructure asset management (IAM). Using a case study approach, we investigated the effectiveness of IAM of a provincial agency in the Netherlands. One of our main findings is that the agency faces difficulties in formulating infrastructure objectives which are linked with overall goals of the agency and commonly shared within the agency. Without such objectives, it is difficult to assess the performance and condition of the infrastructure assets and judge the effect of intervention measures. For effective IAM the continuous optimization and alignment of infrastructure objectives, interventions and situation is essential.

Keywords: infrastructure asset management, public agency, case study

1. Introduction

The performance of the road networks strongly affects the distribution of resources and goods, the accessibility and economic development of regions, the mobility of the citizen and the environmental consequences of road traffic. At the same time, public agencies continually allocate large budgets for the maintenance, renovation and reconstruction (MR&R) of the road network and its components (e.g. pavements, bridges, culverts, signs) to guarantee a performance level of the entire network that contributes to the economic strength and social viability of regions. Cost-effective planning and execution of MR&R activities and projects represent essential tasks of public agencies, and therefore public agencies need to implement effective infrastructure asset management [1].

Infrastructure asset management (IAM) involves activities and decisions that reduce the expenditures over the life-cycle of an infrastructure asset while extending the period for which the asset provides its required performance [2], [3]. The decision context of IAM is characterized by three main aspects which have to be optimized and aligned:

infrastructure objectives, infrastructure interventions (MR&R), and the infrastructure situation. Public agencies implement effective IAM if:

- Infrastructure objectives are used to evaluate the situation of infrastructure assets
- Infrastructure objectives are translated into infrastructure interventions
- Infrastructure interventions take the current and future situation of infrastructure assets into account
- Infrastructure interventions result in an infrastructure situation which is conform to the infrastructure objectives
- Infrastructure objectives are evaluated based on the infrastructure interventions applied and unexpected changes of the infrastructure situation

Feedback regarding the infrastructure intervention and situation with respect to infrastructure objectives is particularly essential for the effectiveness of IAM.

This paper reports on a research project that aimed at elucidating the effectiveness of IAM at public agencies. It presents and discusses the results of case study on IAM at a provincial agency in the Netherlands and particularly shows how this agency addresses and aligns infrastructure objectives, interventions and the situation at hand.

2. Case Study

In our research, we used a case study approach to investigate the effectiveness of IAM at public agencies. Case studies are particularly appropriate if the holistic nature of real-world contexts and largely unexplored phenomena are addressed [4]. Since IAM involves three main interrelated aspects and is embedded in a specific organizational and environmental context, cases are sources of rich data which provide detailed insights into the extent to which public agencies implement an effective IAM. The case this paper reports on is a provincial agency in the Netherlands which is responsible for the management of 764 km of roads and more than 200 civil engineering objects. Interviews with employees from different organizational levels and units were conducted. In addition, policy documents, maintenance contracts, inspection reports, and planning documents were analyzed. In the following we will describe and discuss how the province addresses and interrelates the three aspects of infrastructure management.

2.1 Infrastructure objectives

Infrastructure objectives determine the criteria for the evaluation of the infrastructure intervention and situation and contribute to the overall objectives of public agencies with regard to mobility and transportation. The provincial agency under investigation formulated an overarching policy for traffic and transport which set the framework for infrastructure objectives. An overall vision was formulated and several instruments were given through which the vision was to be put into practice. These instruments included MR&R.

Although in the policy the direction for infrastructure management is given, infrastructure objectives are not directly specified. With the policy for maintenance quality, the provincial agency indirectly defines infrastructure objectives for the daily maintenance. The agency applies a calculation method for maintenance costs compiled by a nationwide institution for infrastructure. The starting points of this method are four quality levels for infrastructure objects such as roads and waterways: optimal, good, average, fair. The quality level average is defined as what is prevalent in the Netherlands. The quality levels are linked with 6 infrastructure objectives: safety, accessibility, convenience, appearance, quality of life, and environment. By choosing a specific quality level, a statement is made about the objectives to be achieved. The relationship between quality level and infrastructure objective for roads is depicted in Table 1.

	Quality level			
Infrastructure objective	Optimal	Good	Average	Fair
Safety	Minimal risk of accidents	Low risk of accidents	Low risk of accidents	Low risk of accidents
Accessibility	Accessibility not at risk	Accessibility not at risk	Accessibility partly restricted	Accessibility restricted
Convenience	Very convenient	Convenient	Convenient	Somewhat convenient
Appearance	Very good appearance	Good appearance	Sufficient appearance	Moderate appearance
Quality of life	Quality of life not at risk	Quality of life not at risk	Quality of life not at risk	Quality of life partly at risk
Environment	Environmental danger as low as possible	Environmental danger lower than law	Environmental danger according to law	Environmental danger according to law

Table 1. *Quality level and infrastructure objectives for roads.*

In its policy for maintenance quality, the provincial agency formulated a quality vision for roads which aims at an average quality level for all road maintenance work except for winter maintenance (good quality). This quality vision is further specified in the policy for daily road maintenance which translates the infrastructure objectives into sub-objectives, provides indicators and maintenance norms to achieve these sub-objectives, and calculates maintenance cost based on the norms. However, the policy does not include renovation and reconstruction work, nor does it include a maintenance policy for civil engineering objects and waterways.

Besides incompleteness, the policy for maintenance quality and the policy for road maintenance are not consistent and concerted. Since the provincial agency uses a general method for formulating infrastructure objectives, both policies are not directly based on the overall policy for traffic and transport. Some of the infrastructure objectives such as safety and accessibility are not deduced from the traffic and transport policy, although the policy gives guidance for these objectives. For example, in the traffic and transport policy the safety objective is stated as having “not more than 32 traffic deaths and not more than 300 injured who need a hospital”, whereas the safety objective in the maintenance policy is formulated as “low risk of accidents”. For other objectives such as appearance and quality of life it remains completely unclear which relationship they have to the overall mobility policy of the provincial agency. The same holds true for the infrastructure objectives to be achieved (Table 1), which are also taken over from the general method. Most striking is the way of determining the objectives. First, a quality level is chosen which leads to a specific objective. In other words, the means define the objectives. Since the objectives of the general method are non-specific, the provincial agency couched additional sub-objectives and indicators to allow for measuring and monitoring. For example, the general safety objective “low risk of accidents” is transformed into the sub-objective “no accidents caused by pending maintenance”, and road roughness and levelness are chosen as indicators. However, given the definition of safety – extent to which accidents are prevented – road roughness and levelness do not represent indicators but rather means to achieve the safety objective. The objective itself is measurable (no accidents) and does not need any indicators. There are also objectives which are not directly measurable such as a convenient infrastructure for which indicators are required to determine whether the objective is achieved. If for example convenience is defined as the extent to which road users experience the infrastructure as comfortable, the number of road user complaints may serve as indicator. The provincial agency, however, identified signage and drainage as indicator for convenience, which in fact are again means to ensure a certain level of convenience.

2.2 Infrastructure interventions

Infrastructure interventions aim at changing the situation (function and performance) of an infrastructure asset in such a way that formulated infrastructure objectives can be met. The provincial agency conducting this study distinguishes between three major types of intervention which are separated as to organization and to budget: daily maintenance, renovation and reconstruction. Daily maintenance includes short-term maintenance work (< 1 year), which can be both corrective and preventive. It primarily aims at maintaining the performance of the infrastructure asset and removing unsafe traffic situations which occur unexpectedly. Renovation also includes corrective or preventive activities but is planned and carried out in a medium-term period (1 – 5 years) with the aim of maintaining or improving the performance of the infrastructure. For most civil engineering objects the annual budget is the basis for the work planning. If there are no unsafe situations expected, the budget which has remained stable over the years determines the amount of work to be done. The starting point for the annual renovation planning of roads is the deterioration and based on that, the remaining lifetime of single road sections. By combining several sections, an attempt is made to find the technically and economically optimal renovation planning. The annual budget represents the major constraint in this regard. Reconstruction work has a long-term orientation (> 5 years) with again a corrective or preventive nature. Often the aim is to improve the performance or change the function of the infrastructure. The planning of reconstruction projects is a continuous process which often takes several years due to the major impact the project has on the infrastructure environment.

Although the three interventions suggest a logical delimitation, each intervention option is characterized by a process starting with the collection of information about the infrastructure situation, followed by the planning of the work to be done and the determination of the required budget. Each work process shows uncertainties which cause changes in the extent of work or the time planning. As a consequence, all three interventions show some overlap with each other. A clear separation of budgetary and organizational responsibility appears to be difficult. For example, the policy for daily road maintenance applies a long-term perspective through which actually renovation or reconstruction work is described.

2.3 Infrastructure situation

In order to apply an effective infrastructure management, a public agency needs to know the situation of the infrastructure. That includes the current and future technical condition and performance of the infrastructure, the public and economic value, the cost and risks. The situation determines the interventions that are required to attain the infrastructure objectives and is the starting point for evaluating the attainment of these objectives. The provincial agency uses different ways of measuring and monitoring the conditions of their infrastructure assets. Besides daily inspections through which unexpected occurrences are detected and kept in weekly reports, roads and civil engineering objects are annually inspected. Civil engineering objects are visually inspected, whereas for roads specific measuring methods and tools are available and used. For both roads and civil engineering objects the inspection data are stored in databases. The database for civil engineering objects only indirectly reveals the development of the infrastructure condition by listing the observations made during the visual inspections. The data of the road inspections on the other hand are used to calculate the remaining lifetime of road sections and to determine the moment when maintenance work is necessary. For this calculation the provincial agency can make use of specific deterioration models provided by the aforementioned nationwide institute for infrastructure. The calculation methods also allows for linking the condition development to the four quality levels (see Table 1). For civil engineering objects the quality is evaluated by employees and is based on their knowledge and experience. This knowledge also plays a role in assessing the uncertainties connected with the deterioration and performance development of infrastructure. For many, component deterioration is an ongoing process which does not immediately lead to an unsafe situation. Although the provincial agency is conscious of possible political, social and technical changes and their impact on performance and condition of the infrastructure assets, a risk analysis of these factors is not conducted.

Since clearly defined quality levels for civil engineering objects and their components do not exist, the provincial agency cannot objectively state whether maintenance is deferred. Deferred maintenance is a judgment made by single employees. There are several deviating meanings and consequently discussions about the necessity, extent and time of maintenance. For roads quality levels are defined by the nationwide institute for infrastructure. Moreover, discussions arise about the kind of intervention activities to be applied. The quality levels can be achieved by different intervention means that have different consequences for future interventions and finally for the MR&R costs. For example, the safety of a road section can be attained by preserving means. Over the short-term such means are less expensive than more constructive interventions. Over the long-term they may have a stronger budgetary effect since they need to be applied more often. Furthermore, by choosing preserving, this means the actual damage is likely to remain, and it will become worse and require much more extensive and costly interventions. Without agreement on the quality levels and the time in which the required interventions are done, the extent to which maintenance is deferred is hard to determine.

2.4 Alignment of IAM aspects

Infrastructure objectives, interventions and the situation cannot be considered separately. For effective infrastructure asset management all three aspects need to be optimized and aligned to each other. For the provincial agency the relationship between the three aspects is not clear. Particularly the relationship between infrastructure objectives and the other two aspects is weak. The reason is that there are insufficiently formulated objectives for the management of infrastructure assets. Thus, an assessment of infrastructure condition and performance is hardly possible, and decisions on intervention options are difficult to support. For example, the budget for road renovations has been increased in the last years in order to cope with the accelerated deterioration. However, without a comprehensive set of infrastructure objectives the increased budget cannot be vindicated and the effect of its usage on road performance cannot be determined. It remains unclear what the current road performance is and which future quality level the province is striving for. Since there are no objectives defined, employees have different perceptions of whether maintenance is deferred and to which extent.

The policy for road maintenance is intended to translate infrastructure objectives into interventions for daily maintenance. The frequency of interventions to achieve a certain quality level is provided. Most of these frequencies, however, have a medium-term or long-term perspective. That makes it difficult for employees monitoring and maintaining the infrastructure on a daily basis to implement the interventions. It becomes much more difficult without a clear picture of the current infrastructure situation.

Infrastructure objectives can change and can also alter the way of doing MR&R. For instance, there are hardly any discussions about the effects of an altered mobility policy on the intervention options. In addition, objectives can show conflicts with each other. For example, noise reducing asphalt has to be replaced more often than traditional asphalt with the consequence of much more traffic disturbance. Again, discussions about the prioritization of objectives are lacking. Discussions only take place if the reserved budget is seen to be insufficient.

To some extent, the relationship between infrastructure situation and intervention is clearly addressed. The reason is that many employees have been working for the provincial agency for a longer time. They have much knowledge and experiences about inspection, maintenance planning and intervention implementation. This knowledge and experience, which is mostly implicit, determines the employees' picture of what good maintenance is, Based on this picture, employees make decisions and choices. For example, although infrastructure objectives and their importance are not explicitly formulated, several criteria are used to prioritize MR&R work due to the restricted budget. Safety has the highest priority and MR&R work which resolves unsafe situations is carried out first. Moreover, employees try to combine MR&R work to minimize traffic disturbance. However, these prioritizations tend to be more implicitly assumed than explicitly determined.

3. Conclusions

Effective infrastructure asset management aligns infrastructure objectives, interventions and the situation. The case of a Dutch provincial public agency revealed that in particular, missing objectives for MR&R cause divergent and conflicting views within the agency on the position of MR&R and its consequences for the MR&R budget and provision. There is a missing link between the overall strategic objectives of the agency and the importance of MR&R to achieve these objectives. Moreover, the provincial agency faces difficulties to set these objectives in such a way that they are conclusive, measurable and linked with the overall mobility strategy. That can be traced back to the implicit knowledge and experience employees have on performance and the technical condition of the infrastructure assets. There is no common and explicitly shared vision on the quality of infrastructure and the consequences different quality levels have for infrastructure performance. We conclude that within road agencies, a common understanding needs to be developed on the road performance to be achieved, the technical conditions and the infrastructure interventions to ensure the desired performance. Furthermore, performance measurements systems need to be installed which continually monitor the achievement of objectives and the impact of interventions measures.

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The German approach to bridge management: from reactive to predictive management procedures

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Abstract

The German Bridge Management System (BMS) contains assessment and optimisation procedures on object and network level which take into account the results of regular inspection. In principle the BMS is characterized by reactive procedures since it bases on existing damages. Specific risks of older structures are well-known but currently remain out of consideration and lifecycle-oriented maintenance strategies are only covered in a limited way. For an optimized lifecycle-management predictive and risk-based approaches are essential. This includes system and risk analysis of existing structures as well as risk based inspection procedures which could form the basis for well-founded lifecycle-oriented maintenance strategies. Non-destructive testing (NDT) could serve as a basis for efficient and sustainable management of structures.

Keywords: Bridge management, risk, lifecycle, system analysis, optimization, NDT

1. Introduction

It can today be said with certainty that a high-quality road infrastructure is a fundamental precondition for an industrial society, insofar as it creates prosperity and provides citizens with a commensurate quality of life. As Europe grows economically and culturally closer together, the road infrastructure will come under even greater strain. Conditions in Germany are changing as well. Already low disturbances in the road network by traffic restrictions or by the failure of single structures lead to strong obstructions of traffic with considerable economic subsequent costs as well as to negative effects on the environment. Lifecycle-oriented road infrastructure management is indispensable.

In Germany this is particularly true for the federal road network which carries the main load of the transit traffic by reason of its central position in Europe and it will have to take traffic increasing loads in future due to the further development of the European market. With an asset value of currently approx. 170 bn Euros this road network represents considerable fixed assets. About 45 bn Euros fall to bridges and engineering structures whereas bridges represent the most important part. Among other structures there are currently 38.288 bridges with a bridge deck area of around 28 Mio m². Most of them are prestressed concrete bridges (around 70%).

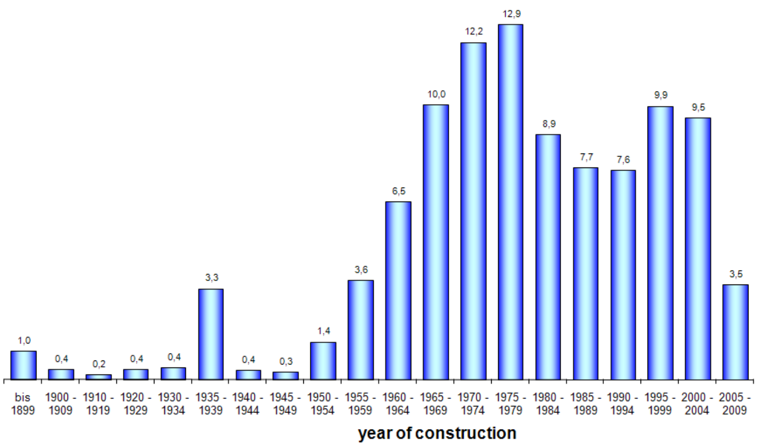

Figure 1. *Age distribution of Federal road bridges in Germany (1 September 2008).*

The main part of the bridges was built in den 60th up to the 80th of the last century (see Figure 1). Despite the planned lifespan of more than 70 year, these bridges show major damages after a time period of 30 to 40 years. At that time our current knowledge about the durability of structures was not available. Construction and design principles are subject to continuous improvement towards avoiding faults. Over the years a very high quality of construction methods was achieved. Nevertheless maintenance needs today are in the range of 1 % of the fixed assets which represents about 450 Mio € per year.

The maintenance programs prepared for this purpose not only require a high budget, but also influence the traffic infrastructure and, thus, the economy and society as a whole. The present safety of the structures has to be ensured under consideration of environmental aspects. At the same time the structure owner has to make sure that the maintenance activities are carried out in the most efficient way. Considering the fact that financial resources are restricted, the maintenance costs have to be spent in a way to obtain the greatest possible benefit. This task is supported by the application of a Management System which is described in the following.

2. Current status of bridge management in Germany

As a tool to support a cost efficient and sustainable maintenance management a Bridge Management System (BMS) is developed with the aim to implement a systematic maintenance approach according to nation-wide uniform criteria. In this context instruments which enable the stakeholders involved in the maintenance process are being developed to plan, steer, control and check the complex process on time. Systematic bridge maintenance is understood as a process. Starting from bridge stock and condition data resulting from regular bridge inspections damage analyses and deterioration forecasts can be made. After checking of possible maintenance strategies a priority ranking and a program formation plus provision of the required financial means is carried out. Documentation of the achieved results and balancing of accounts follows the project planning and the execution of construction work.

All structures have to be inspected in certain intervals. According to the German Standard DIN 1076 [1] distinctions are made between main inspections, simple inspections, inspections on special occasions, inspections according to special regulations and regular observations. Main inspections are regularly carried out every 6 years; simple inspections are to be carried out 3 years after a main inspection. The main inspections are executed as visual inspections with a hand near examination of the complete structure.

The results of the inspections are collected in the database SIB-Bauwerke (Road Information Database – Structures), which contains technical data concerning construction type and characteristics according to the guideline ASB [2] as well as information on damages for each bridge in the network according to the guideline RI-EBW-PRÜF [3]. Each individual damage noticed during the inspection is assessed using a 4-stage scale for the valuation criteria stability, traffic safety and durability. From these information a condition index is derived in the range of 1.0 (very good condition) to 4.0 (insufficient condition). Figure 3 shows the current distribution of condition index for structures in the federal road network.

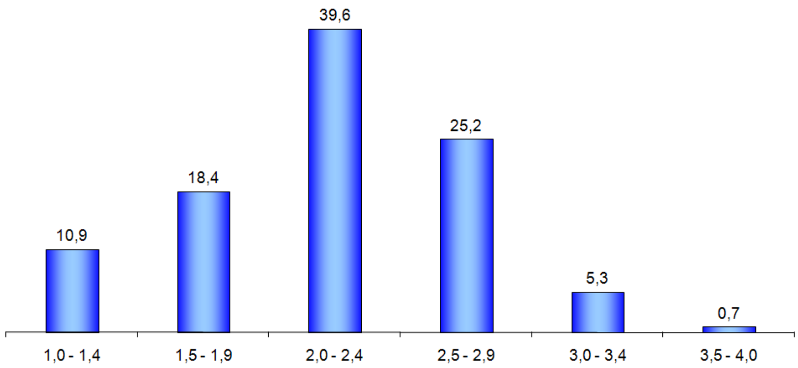

Figure 3. *Condition index [% of bridges] (1 September 2008).*

Besides construction data current information about the condition of the bridges forms the basis of current systematic maintenance planning. The databases contain extensive information about the different structures. Additionally information e. g. the geographical position, clearance, signposting and traffic volumes are included. All data are recorded by the local road administrations, updated every half year and handed out to the Federal Ministry of Transport for network wide evaluation and controlling.

The actual BMS is a comprehensive management system for structural maintenance. It is developed as a tool for all stakeholders of road administrations and federal institutions. It provides state authorities with draft maintenance plans required to obtain improvements at project level, to maintain structures in an acceptable condition and to meet network level strategies, long term objectives and budgetary restrictions. The federal ministry is supported by comprehensive information on the current condition of structures, by estimation of future funding requirements and by developing strategies for achieving long-term objectives [4, 5].

The BMS for state authorities falls under the bottom-up type. Object related analysis and assessment procedures take place based on the results of inspection according to DIN 1076. Subsequently the results are optimized on network level and integrated in network-wide maintenance programs. Coordinated computer programs provide the subsequent programs with first results. Transparency is guaranteed and the inclusion of additional data as well as direct intervention, e.g. fixed maintenance measures into the calculation processes is possible. The existing database SIB-Bauwerke and the common road databases (e.g. TT-SIB, NW-SIB) are integrated. The system is composed of 4 interconnected modules (see Figure 3).

- BMS-MV (measure variants) for the supply of all the information needed by subsequent computer programs. The module proposes technically reasonable measures for damages observed on the structures at hand and provides information on costs and consequences.
- BMS-MB (measure evaluation) for evaluation of maintenance alternatives on object level. This module performs cost/benefit-analysis for each combination proposed by BMS-MV. The output of the analysis on object level - measures and measure combinations with associated costs, benefits and effects to the condition state of structures – is transferred to the network level for further optimization.
- BMS-EP (maintenance program) for optimization of maintenance planning on network level and presentation of maintenance programs. This module is responsible for choosing the best combination of measures for each year of the planning period of 6 years (short term optimization).
- BMS-SB (scenario building) for evaluation of object related maintenance strategies on network level. This module is designed for medium and long term prediction of maintenance costs and condition states for given different maintenance strategies.

At federal level information from the database BISStra (Federal Road Information System) which contains amongst others all structural data and the results from the state level planning process are considered. The BMS for federal authorities fall under the top-down type. Currently long term expenditure forecasts are prepared, analyzed and updated, the draft maintenance programs, drawn up at state level, are analyzed and rated and annual statements of performed maintenance measures are evaluated. The investigations result in the available budget, direct interventions into the maintenance practice and updating of technical rules.

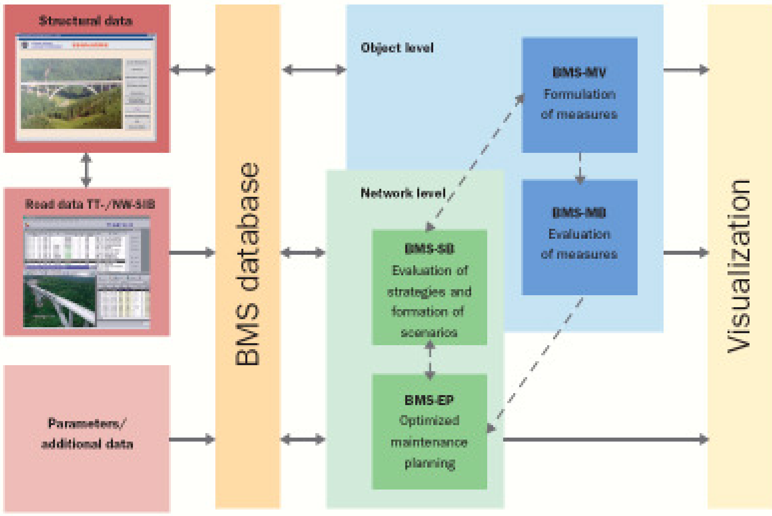

Figure 3. *Bridge Management System (BMS) in Germany*.

3. Challenges

Current maintenance strategies aim at remediation of existing structural damages and securing traffic safety. Future effects are only covered with respect to the prediction of condition development and its effect on the prospective maintenance budget in a deterministic mode. Insofar future developments and demands are barely considered, although today the course is set for an effective and efficient future road infrastructure.

Initial point of substantial investigations at BASt is the fact that according to current forecasts heavy goods traffic will increase by about 84% up to the year 2025 referring to the conditions of 2004 [6]. Additionally the quantity of heavy goods vehicles (HGV) increases every year dramatically and there is a pressure from the transport industry to introduce new vehicle concepts, the so called “Gigaliner” or “Road Trains” which could reach a maximum weight of 60 tons. The bridges are not designed for this purpose [7].

The bridge stock in Germany is inhomogeneous in terms of load bearing capacity due to changing load models and design codes over the years. Since 2003 bridge design corresponds to the Eurocodes (ENV-prestandard), which takes the current traffic into account, but only 2% of the bridge stock is designed according this load model. Most of the bridges have even smaller load bearing capacity.

Analytical investigations by stochastic traffic simulation which in fact consider the current heavy goods traffic showed that a number of the older bridges (bridge class “60” and lower) can have remarkable structural deficiencies. In Figure 4 a comparison of simulation results and design capacity is compiled for multi span bridges. The moments at the support are given in relation to the span width of the bridges. Obviously only the newest bridges are designed appropriate to the current traffic situation. A lot of the older ones are underdimensioned and to ensure the expected service life, these bridges have to be investigated in detail and probably strengthened. First estimations result in costs of more than 1 bn €.

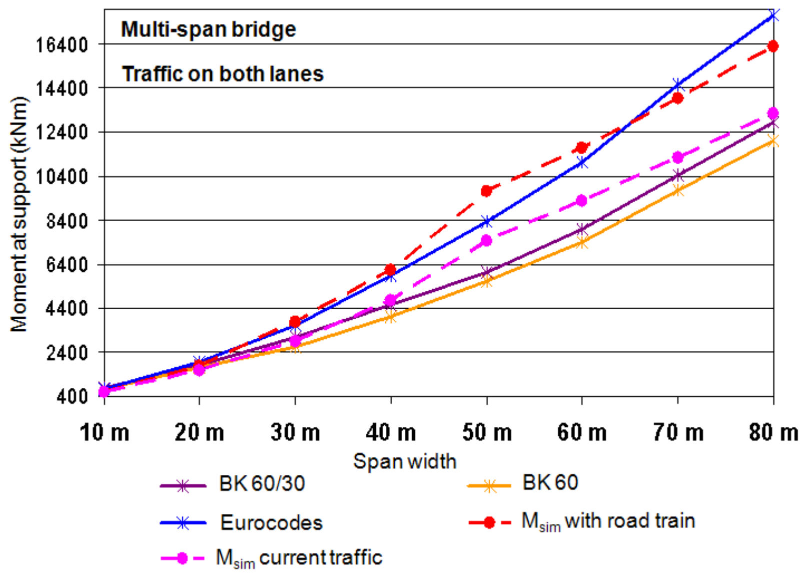

Figure 4. *Design capacity and results of traffic simulation.*

Additionally the older prestressed concrete bridges show – until that time unknown – severe weak points with regard to former design rules and materials used [7]:

- Low load bearing capacity due to unconsidered temperature gradient in design.
- Low shear force capacity due to marginal shear reinforcement.
- Fatigue effects of tendons in coupling joints.
- Rupture of tendons due to stress corrosion effects associated by imperfectly grouted ducts.

As mentioned before deficits are only included in current maintenance programs if damage effects become visible. Primarily this approach has been implemented to manage the road infrastructure network with respect to deterioration. Risks are considered indirectly by assuming that interventions are always performed on the deteriorating infrastructure component before the probability of failure reaches an unacceptable level. While such an assumption may be valid for well-managed structures without deficits and exposed to unchanging loads, this approach is unsatisfactory to structures containing structural deficits and subjected to increasing loads for which they were not designed. Thus to manage a heterogeneous bridge stock subjected to both potential deterioration processes and increasing loads, a risk assessment and prioritization approach must be considered.

4. Future development

In view of the urgency of the matter currently the vulnerability prone bridges are identified so that funding for detailed investigations, operational measures, strengthening or replacement can be estimated and allocated. For this reason the bridge stock is screened with the help of the database SIB-Bauwerke to filter the bridges according to their load bearing capacity, their shear force capacity, the used system of tendon coupling and the used tendon steel type. Based on these results the identified structures are assessed by taking the potential failure consequences into account. This procedure could be characterized as a qualitative vulnerability assessment approach.

In future a broader management approach will be sought, which covers detected damage and condition effects as well as demands from future traffic and the existing structural deficits mentioned before. Basic idea is that both actions (E_i) and resistance (R_i) of structures are time-dependent and random parameters. Typically probabilistic analyses result in failure probabilities (P_{fi}) which should not increase a pre-defined target failure probability ($P_{target\ i}$) [9]:

(1) $$P_{fi} = P(R_i - E_i) \leq P_{target\ i}$$

Risk assessment broadens this approach by introducing the risk of failure for a given structure or component which can be computed by multiplying the failure probability by the consequences of failure:

(2) $$Risk_i = P_{fi} \bullet consequences_i$$

Consequences of inadequate performance can be transferred into owner, user and environmental costs (C_o C_u and C_e). Then the vulnerability of a structural component i experiencing failure due to a given load is defined as:

(3) $$Vulnerability = (P_{fi|E}) \bullet (C_o + C_u + C_e)$$

Thus with adequate information concerning the existing resistance, the probability of critical actions and its consequences both, the component risk of failure and the risk of failure of the overall transportation link can be determined. An example is given in [9] where the vulnerability assessment of road infrastructure subjected to natural hazards is presented.

The extent of failure consequences is influenced by indication effects. If a failure could occur without indication, e. g. the sudden collapse of a bridge, the consequences could be enormous. Even in cases with low failure probability, the risk of failure could be comparatively high. As a consequencea high priority regarding repair should be allocated to these bridges.

If resistance and action parameters are recorded sufficiently for example by inspection or monitoring, optimized maintenance strategies including well balanced protective measures could be derived, which may lead to decreasing maintenance costs and an increase in service life (Figure 5).

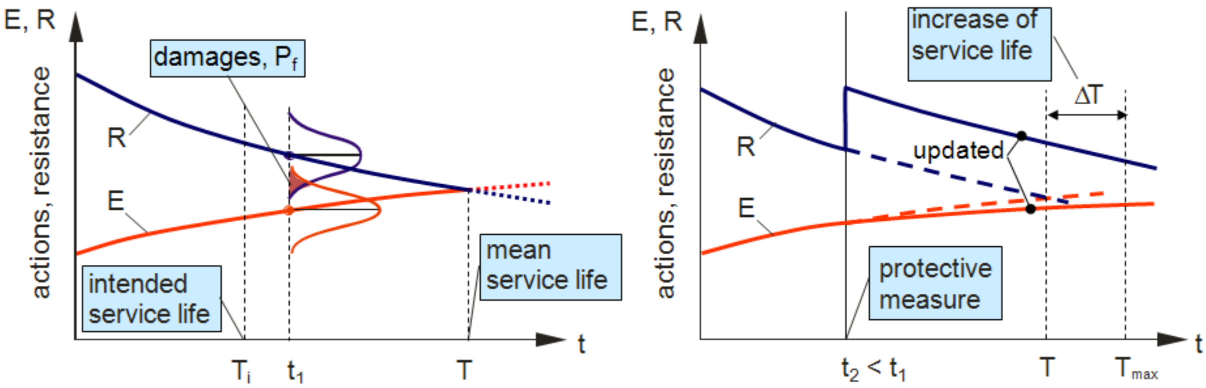

Figure 5: *Deterioration, damage and increase of service life [10].*

The proposed risk based maintenance management consists of 3 essential steps:

- First of all and as a basis for the following steps a comprehensive risk analysis of the given structures has to be performed. The probability of potential damages and the probable consequences have to be derived. This step considers the determination of current and expected traffic loads, well known deterioration effects, e. g. chloride corrosion, and the given structural deficits mentioned before. Here the experience of the professional and the requirements of the owner have to be taken into account also. This is also related to combination of actions and existing deficits and damages which have to be closely examined by a comprehensive system analysis.

- For given structures the risk analysis gives information about critical structural elements, relevant damage mechanisms and time dependencies. This forms the basis for the second step, a risk based inspection regime in which frequency and extent of inspection is variable and adapted. The common inspection procedures described above will be enhanced by application of non-destructive testing methods and monitoring with adapted sensors for in depth investigation of critical structural elements.

- Thirdly a procedure for optimization of maintenance strategies will be derived. A basic approach is drafted in Figure 6. Decreasing maintenance expenses lead to both increasing failure probability and loss expenses. If maintenance costs and loss expenses don't compensate each other, a cost minimum can be expected which represents an optimized strategy if the failure probability at cost minimum is lower than the target failure probability. This simple approach has to be extended by taking the individual risks, possible maintenance strategies and their lifecycle costs into account. In addition to owner costs a full cost approach would consider user, climate and environmental cost aspects too.

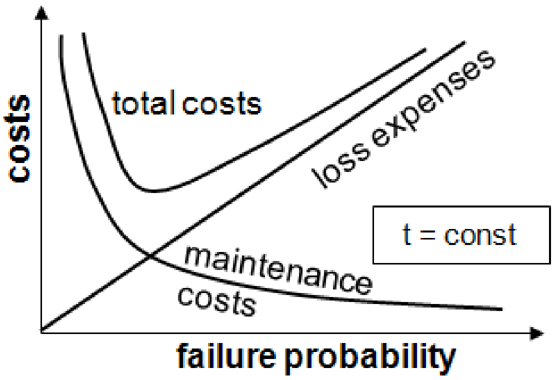

Figure 6: *Cost optimization [10].*

5. NDT for efficient management of structures

As a basis for risk management there is ample demand for methods to establish the condition of structures before severe damage has occurred. For inspections, NDT-methods should be able to provide a relative quick and inexpensive means to establish whether a structure is still in a serviceable condition or not.

Today in the field of inspection and analyses of structures sophisticated NDT-methods are applied in the frame of special investigations only, if common inspection procedures are not effectual and if severe damage is assumed or already visible. This covers the application of sonic and radar devices to localize prestressing reinforcement and to detect damaged areas, electric methods to detect corrosion, magnetic methods to detect ruptures in steel elements and the use of high speed laser scanning devices for inspection of road tunnels. However usual NDT-investigations on structures are time consuming and may lead to considerable disturbances of the traffic [11].

To speed up inspections automatic and scanning NDT-methods are badly needed. The results of investigations on high speed laser scanning devices for inspection of road tunnels and on scanning radar and sonic devices for large scale concrete surfaces showed, that these methods could bring real benefit for risk based inspection regimes (see Figure 6). As well it appears feasible to construct a vehicle-based measurement apparatus with radar and magnetic measurement head for non-destructive estimation of moisture and chloride contamination of the reinforced concrete of paved bridge decks [12].

Against the background of the increasing age of bridge stock and decreasing maintenance funds an optimized maintenance planning gains in importance. Today a primarily reactive management system is applied, which uses empiric or deterministic deterioration models in connection with visual inspection as described above. In future risk based approaches probabilistic deterioration models are intended. By NDT-measurements the uncertainty of models and input parameters could be reduced successively and predicted values could be improved. Compared with traditional visual inspection NDT-methods have the advantage to detect potential damages at an early stage. Then adequate measures could be induced before severe damages occur.

FIGURE 6. *Ultrasonic-scanner for application on bridge decks and inside a box girder.*

Closely connected with these ideas are considerations of a future Life-Cycle-Management. NDT-measurements could be included here for contribution of relevant parameters and their expected development. This could also form a robust basis for infrastructure management in the frame of PPP-projects. The added value of NDT in PPP-models differs if a new structure or the transfer of an existing one is intended:

- New structures: application of NDT in the frame of quality assurance and control, “Birth Certificate”, initial point of Life-Cycle monitoring, early detection of deficits.

- Existing structures: NDT for condition assessment, estimation of lifetime, extrapolation of condition changes.

5. Conclusions

The road infrastructure network is of vital importance for the society and economy as a whole. Passenger transport and the exchange of goods call for an efficient, safe and environmentally appropriate infrastructure. However, the present status of the land-based transport infrastructure shows many deficiencies:

- Technical progress also results in changing functional demands on the existing transport infrastructure. If designers, contractors and road authorities are not responding to them, the level of service will diminish resulting in various inefficiencies. They affect both the users individually and the economy as a whole.

- Growing traffic demand is linked to more standardized technical and legal requirements. The transport systems in Europe will be more and more harmonized which is still not the case for the underlying “hardware”. Therefore, the management of the transport infrastructure can not be commissioned exclusively to local entities. It urges for a more holistic approach.

- Existing road infrastructures have to be maintained that consists of many inappropriately designed or constructed structures. Not all negative impacts on safety and security can be mastered or are already identified. So far as they are known, efficient risk management is not in place everywhere due to missing management knowledge.

In the face of European mega trends according economic, social and environmental aspects the German road infrastructure management has to be adapted. Future challenges have to be anticipated today. There is a strong need for road infrastructure to be “fit for the future”. Relevant areas are:

- Maintenance strategies to meet future demands concerning heavy goods traffic. Relevant criterion for bridge management in Germany is not only the condition index but also load bearing capacity and structural deficits.

- Improvement of management tools to meet future demands. There are still open questions in the field of maintenance planning which have to be solved concerning risk management and reliable probabilistic approaches.

- NDT for efficient and sustainable management structures. There is a need for sophisticated methods to find out structural problems before severe damages occur without hindrance of traffic flow. NDT measurements should also serve as a basis for Life-Cycle management procedures.

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Multi-Comfort House – an example of the building concept for sustainability

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Abstract

Multi-Comfort House is a building concept, which includes energy performance criteria set in accordance to the Finnish Passive House definition. The term "Passive House" refers to a voluntary target for the energy performance of a single building, aiming at significant reduction of heating energy demand compared to the current construction practices. As an approach to sustainable building, it emphasizes energy-savings by an air-tight and well-insulated building envelope as well as an effective heat recovery in the ventilation. The simulation results of the first Finnish Multi-Comfort pilot building, a single-family house in Nummela, indicate that the criteria for the energy performance can be met in an average-sized house in the Southern Finland. The energy demand of the pilot building was calculated with the dynamic simulation software IDA ICE 4.0, which was also used for the analyses of the thermal comfort inside the house.

Keywords: Passive House, Multi-Comfort, energy-efficiency

1. Introduction: The Passive House approach

Within the various approaches to sustainability, the Passive House aims at significant reduction of heating energy demand by improving the properties of the building envelope and by introducing an efficient heat recovery in the ventilation. The definition is based on the total energy approach, which will be applied in the Finnish building code in 2012. The heating energy demand of a Passive House is low enough for ventilation heating. [1]

In the Northernmost parts of the Europe the international Passive House criteria lead to solutions, which are not economically viable. For this reason Sweden [2], Norway [3] and Finland have introduced their own, national Passive House definitions. The VTT researchers introduced the suggestion for the Finnish Passive House definition in the research project *PEP – Promotion of European Passive Houses* in 2006. The Finnish Passive House is defined by three criteria, which are:

- Heating energy demand ≤ 20 - 30 kWh/(m²a) depending on the location
- Total primary energy demand ≤ 130 - 140 kWh/(m²a) depending on the location
- Air-tightness n_{50} ≤ 0.6 1/h

The floor area used in the definition is gross floor area. [4] The first pilot buildings meeting the criteria of the definition were completed in 2009.

		THE FINNISH PASSIVE HOUSE DEFINITION			THE INTERNATIONAL PASSIVE HOUSE DEFINITION
CLIMATIC ZONE		SOUTH	MIDDLE	NORTH	
HEATING ENERGY DEMAND max.	kWh/(m²a)	20	25	30	15
TOTAL PRIMARY ENERGY DEMAND max.	kWh/(m²a)	130	135	140	120
AIR-TIGHTNESS n50 max.	1/h	0.6			0.6
FLOOR AREA		GROSS FLOOR AREA			TREATED FLOOR AREA
CALCULATION TOOL		CAN BE SELECTED			PHPP

Figure 1*. The International Passive House criteria and the Finnish Passive House definition as suggested by the VTT researchers in the research project PEP – Promotion of European Passive Houses. The floor area is calculated as treated floor area (wohnfläche) in the international Passive House definition and as gross floor area in the Finnish Passive House definition.*

2. The Multi-Comfort concept

Multi-Comfort is a concept by Isover Oy for new constructions. It sets a requirement for the energy performance of a building in accordance to the Finnish Passive House definition.

The heating energy demand of a Multi-Comfort house is max. 20 – 30 kWh/(m²a) according to the location, as in the Finnish Passive House definition. As the national primary energy factors are not confirmed, the Multi-Comfort concept does not at this stage set any criteria for the total primary energy demand, but the calculated total energy consumption should not exceed 130 kWh/(m²a). The total energy consumption is calculated as so called ET-value according to the Finnish building code. In addition, the Multi-Comfort concept gives recommendations for air-tightness (max. 0.6 1/h) and maximum heating power (20 – 30 W/m² depending on the location). The calculation tool is not specified by the concept. [5]

The first project targeting to meet the criteria of the Multi-Comfort concept is a single-family house located in Nummela, 50 km North-West from Helsinki center. In the Southern parts of Finland the Multi-Comfort house criteria for the heating energy demand is max. 20 kWh/(m²a), and in addition the Multi-Comfort concept recommends the heating power of max. 20 W/m².

		THE FINNISH PASSIVE HOUSE DEFINITION			THE MULTI-COMFORT CONCEPT			
CLIMATIC ZONE		SOUTH	MIDDLE	NORTH	I	II	III	IV
HEATING ENERGY DEMAND max.	kWh/(m²a)	20	25	30	20	22	25	30
HEATING POWER max.	W/m²	NO REQUIREMENT			20	22	24	28
TOTAL PRIMARY ENERGY DEMAND max.	kWh/(m²a)	130	135	140	NO REQUIREMENT			
TOTAL ENERGY CONSUMPTION max.	kWh/(m²a)	NO REQUIREMENT			130			
AIR-TIGHTNESS n50 max.	1/h	0.6			0.6			
INTERNAL HEAT LOAD	W/m²	NOT SPECIFIED			3.1			
FLOOR AREA		GROSS FLOOR AREA			GROSS FLOOR AREA			
CALCULATION TOOL		CAN BE SELECTED			CAN BE SELECTED			

Figure 2*. The Finnish Passive House definition and the criteria of the Multi-Comfort concept. The only requirement of the Multi-Comfort concept is the maximum heating energy demand. Values given for the maximum heating power, total energy consumption and air-tightness are recommendations. The concept also defines the internal heat gains (3.1 W/m²) for the calculations.*

3. The solutions of the pilot project

Figure 3*. Illustration of the Multi-Comfort pilot project in Nummela, Southern Finland.*

The Multi-Comfort pilot project is a single-family house, 179 m² in gross floor area, characterized by the large north-facing windows, which the client family wanted to have for the lake view on the northern side of the house. The rooms are organized in one storey for functional reasons, leading to a relatively high shape factor (A/V) of 1.3 m²/m³. The recommended shape factor of a single-family Passive House is max. 0.8 m²/m³. [6]

The architectural design was an interactive process with the energy simulation. The early simulation results of the sketches indicated, that the heating energy demand would be too high, about 27 kWh/m²a. The architect listed changes, which would decrease the heating energy demand. The changes were simulated and applied in the plan in the order of the client family priorities. The target value for the heating energy demand was achieved by reduction of the window surface area and the room height, improvements of the U-values and introduction of the occupancy-time-based control in the ventilation.

Figure 4. *Floor plan of the Multi-Comfort pilot project.*

The mechanical ventilation has a heat recovery system with a regenerative heat exchanger and the annual efficiency of 74 %. Heat is distributed through floor heating and ventilation. The heating energy for the domestic hot water and the floor heating is generated by an air-to-water heat pump with the COP of 2.6.

The load-bearing exterior walls are constructed of prefabricated wall elements with LVL (laminated veneer lumber) frame. The facade materials are oak panelling with white translucent finish and plaster rendering on ventilated plasterboard. The thermal insulation for the roof and for the floor was installed on site. The ventilated floor structure consists of hollow concrete slabs with thermal insulation on top.

The U-value of the relatively large window surface area was improved by using sealed quadruple glazed units fixed onto the wall frame. This solution was applied wherever an opening window is not necessary and the glass surfaces can be easily washed on both sides. The price per square meter of this 4K-glass unit filled with Argon is less than half the price of a regular Passive House window.

ISOVER MULTI-COMFORT PILOT PROJECT			
PROPERTIES OF THE BUILDING ENVELOPE AND HEAT RECOVERY			
	values in planning phase	**solution as constructed**	**description**
WALL (W/m²K)	0,083	0,083	25+410 mm, Isover insulation
ROOF (W/m²K)	0,053	0,053	25+125+600 mm, Isover insulation
FLOOR (W/m²K)	0,098	0,098	340 mm of Isover Flo + 35 of XPS
WINDOWS (W/m²K)			
opening window	0,8		
fixed window	0,8		
glazed unit (fixed onto frame)	0,5	0,4	4K-13 glazing, Argon-filled
DOORS (W/m²K)			
door	0,7		
door with window	0,7		
openings / orientation south (m²)	8,57	8,57	
openings / orientation east (m²)	9,2	9,2	
openings / orientation west (m²)	11,4	11,4	
openings / orientation north (m²)	18,6	18,6	
openings total (m²)	47,8	47,8	
openings / gross floor area (%)	26,7	26,7	
air-tightness n50	0,5		to be measured on site
HEAT RECOVERY %	74	74	
GROSS FLOOR AREA m²	179,27	179,27	
NET FLOOR AREA m²	146,14	146,14	
HEATED VOLUME m³	469,66	469,66	
GROSS VOLUME m³	860,75	860,75	

Figure 5. *Building envelope properties of the Multi-Comfort pilot.*

4. Simulation results

The energy consumption of the Multi-Comfort pilot building was simulated by Equa Simulation Finland with the dynamic simulation software IDA – Indoor Climate and Energy 4.0 using the climate data of Helsinki.

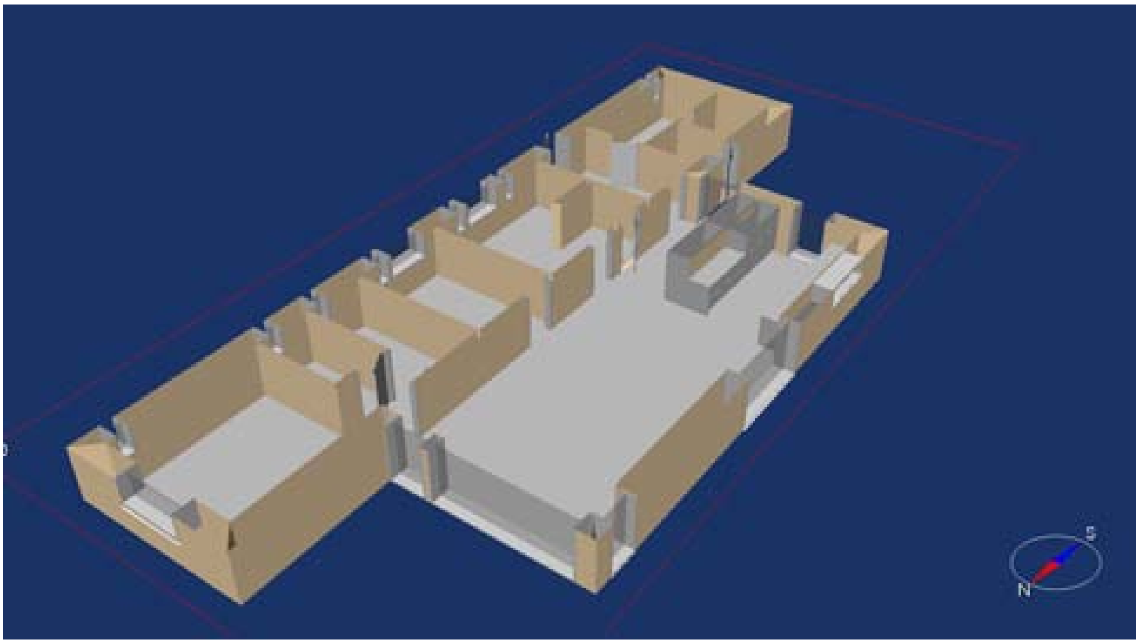
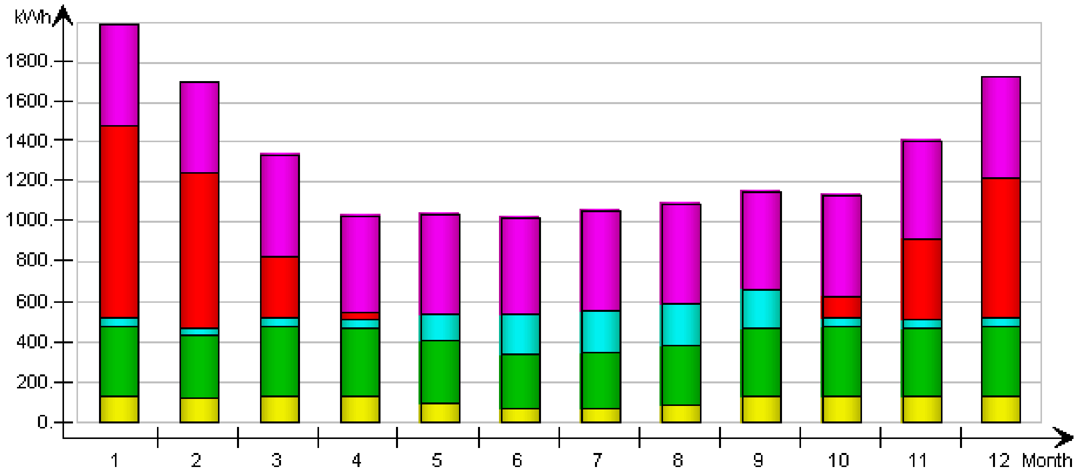


Figure 6. *IFC-model of the pilot building imported in the IDA ICE simulation software. The building information model includes the properties of the building envelope such as the sizes of the doors and windows, U-values and the material layers of the structures.*

The value used for the internal heat load is 3.1 W/m² as required in the Multi-Comfort concept. For the calculation of the indicative primary energy demand, the value 2.1 was used as the primary energy factor for electricity. This has been one of the recent suggestions, although in many countries the primary energy factor for electricity is higher than this.

The terrace roof provides shading for the south-facing windows. The simulation results showed, however, that the summertime room temperatures would be relatively high due to the large windows in the west facade. Thermal comfort was improved by adding external blinds on the west-facing windows. This decreased the percentage of hours when the operative temperature is above 27°C from 25 % down to 13 %. The simulation model did not include the trees, which will provide some extra shading from the low sun angles from west.



		SUPPLIED ENERGY		PRIMARY ENERGY	
		kWh/a	kWh/m²a	kWh/a	kWh/m²a
	domestic hot water	2277,3	12,7	4782,3	26,7
	heating	1279,6	7,1	2687,2	15,0
	HVAC aux	1236	6,9	2595,6	14,5
	cooling	1	0,0	2,1	0,0
	equipment, facility	3856	21,5	8097,6	45,2
	lighting, facility	1349	7,5	2832,9	15,8
	total	9998,9	55,8	20997,7	117,1

Figure 7. *Simulation results of the final design. The table shows the supplied energy and the primary energy. The heating energy demand (without DHW) is 18.6 kWh/(m²a) including both the heating in the spaces and in the ventilation unit. The heating energy is produced in an air-to-water heat pump with a COP of 2.6 resulting to the heating energy consumption of 7.1 kWh/(m²a).*

The total primary energy demand was calculated as an indicative value, though the Multi-Comfort concept does not set a requirement for the total primary energy demand and the Finnish primary energy factors are not defined yet. With the factor of 2.3 (for electricity) the primary energy criteria of a Finnish Passive House (max. 130 kWh/(m²a) in the Southern Finland) could still be met.

		THE FINNISH BUILDING CODE C3 / 2008	THE MULTI-COMFORT PILOT
WALL	W/m^2K	0.24	0.083
ROOF	W/m^2K	0.15	0.053
VENTILATED FLOOR	W/m^2K	0.19	0.098
WINDOW opening	W/m^2K	1.4	0.8
WINDOW fixed	W/m^2K	1.4	0.8
FIXED GLAZING	W/m^2K		0.5
DOOR	W/m^2K	1.4	0.7
HEAT RECOVERY	%	30	74
AIR-TIGHTNESS n50	1/h	4.0	0.5
HEATING ENERGY	$kWh/(m^2a)$	43.6	7.1
TOTAL SUPPLIED ENERGY	$kWh/(m^2a)$	92.3	55.8
TOTAL PRIMARY ENERGY	$kWh/(m^2a)$	193.8	117.2

Figure 8. *Indication of the savings gained: a comparison of the pilot building solutions and the minimum requirements of the Finnish building code 2008 (SRakMK C3 2007). With the current solutions the simulated heating energy consumption of the pilot building is 84 % smaller than with the 2008 minimum requirement level without any compensation. Respectively, the total energy consumption is reduced by 39 % compared to the building code minimum requirements. The COP value 2.6 of the heat pump is applied in both cases. Energy performance is calculated in both cases using a reference value for the air-tightness.*

5. Conclusions

The energy performance criteria of the Multi-Comfort concept were proved to be viable for an average-sized single-family house in Southern Finland. Despite the relatively high A/V ratio, large window surface area and the north orientation of the windows, the criteria for the energy performance can be met. With higher U-values or less effective heat recovery the target level would not be achieved, and the compensation would probably require reduction of the window surface area and compromising the wishes of the client family.

The simulation results also show that the thermal comfort of the interior spaces would be poor without the external shading of the west-facing windows. In the buildings with high level of thermal insulation, extra attention must be paid to the thermal comfort and shading of large windows. Mechanical cooling of spaces would increase the annual energy consumption.

		THE MULTI-COMFORT				THE MULTI-COMFORT
		CONCEPT				PILOT
CLIMATIC ZONE		I	II	III	IV	I
HEATING ENERGY DEMAND max.	$kWh/(m^2a)$	20	22	25	30	18.6
HEATING POWER max.	W/m^2	20	22	24	28	19.4
TOTAL PRIMARY ENERGY DEMAND max.	$kWh/(m^2a)$	NO REQUIREMENT				117.1
TOTAL ENERGY CONSUMPTION max.	$kWh/(m^2a)$	130				
AIR-TIGHTNESS n50 max.	1/h	0.6				NOT MEASURED YET
INTERNAL HEAT LOAD	W/m^2	3.1				3.1
CALCULATION TOOL		CAN BE SELECTED				IDA ICE 4.0

Figure 9. *Based on the simulation results, the energy performance criteria of the Multi-Comfort concept can be met in the pilot building. The pilot building is located in the climatic zone I. The air-tightness will be measured in a standard blower-door test in a pressure difference of 50 Pascal.*

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Trends in Sustainable Building in the USA

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Abstract

Sustainable construction is a large and growing industry in the USA and in the world. In this paper we look at some recent history of green construction in the US, and current trends. Included are rating systems, with a focus on Leadership in Energy and Environmental Design; sustainability challenges such as the Living Building Challenge; and a university level competition to build homes that are completely solar powered, the Solar Decathlon. Buildings have a huge impact on resources and pollution. Sustainable options are available, and we have the capability to make changes. Some changes will be incremental and some will require major changes in the way buildings are designed, built and operated.

Keywords: LEED, Solar Decathlon, construction, sustainable

1. Introduction

In the USA, buildings consume 40% of primary energy, 72% of electricity [1] and 14% of potable water [2]. They also are responsible for 39% of the CO2 emissions in this country. Up through the 1960's energy seemed limitless, and buildings and development paid little attention to efficiency. The oil embargo of the 1970's was a wake up call for some. Most people disregarded energy efficiency within a few years.

Finally in the 90's energy efficiency and environmentally sensitive design started to become mainstream. The US Green Building Council started in 1993, and the following year they and The Natural Resources Defence Council led the way to develop Leadership in Energy and Environmental Design (LEED). LEED has helped to drive the market for design and construction of green buildings. In 2000, Green Globes was introduced, evolving from the Building Research Establishment's Environmental Assessment Method (BREEAM). BREEAM was developed through cooperation of over 35 Canadian firms, universities and governmental organizations.

It is almost impossible to measure the real impacts of a building and very difficult to quantify improvements beyond "less impact is better." There are competing rating systems in the USA, including Green Globe and LEED. There are also a variety of challenges.

2. “Challenges”

Several organizations set up goals to seriously challenge the way we think about, design and construct buildings. These challenges call for performance changes that are revolutionary as opposed to the evolutionary changes in the rating systems we will discuss in the next section.

The “2030 challenge [3]” seeks to reduce fossil fuel use in new buildings by 50% immediately, and total elimination of fossil fuel use by the year 2030. The challenge calls for a concerted global effort. There is difficulty in defining a 50% reduction. Several different baselines are in use.

The “Living Building Challenge” from the Cascadia Region Green Building Council sets a simple goal: meet 16 mandatory elements of design, called pre-requisites4. Defining the pre-requisites ranges from simple to complex. Net-zero energy and net zero water, while challenging to meet, are easy to determine. Others, such as “Beauty and Spirit” are harder to define, and offsetting the “Construction Carbon Footprint” depends on calculations that are not widely accepted. To date, no building has completely met the Living Building Challenge.

3. Green Globes

Green Globes is an on-line assessment protocol, rating system and guidance tool for sustainable building. It rates buildings on a 1,000 point scale in areas of energy, indoor environment, site, water, resources, emissions and project / environmental management. A project that achieves at least 350 points will be rated at one to four globes.

Green Globes includes third-party assessment of design and conducts on-site walkthroughs. The Green Building Initiative, developer of Green Globes, includes a life-cycle analysis tool on their website, www.thegbi.org. Third party assessment and extensive life-cycle analysis make Green Globes very different from LEED.

4. LEED

Leadership in Energy and Environmental Design (LEED) is currently the most popular certification system in the USA. Buildings can be certified under one of several programs. Homes (residential construction), neighborhood developments and commercial interiors can be certified as being designed and constructed to LEED standards. Core & shell projects, new construction, and "schools, healthcare retail" include options for certifying both operations and maintenance as well as design and construction.

LEED for new construction and major renovations, version 3 was launched in 2009. The reference guide is available for purchase. The 108 page "LEED 2009 for New Construction and Major Renovations Rating System [5]" is available as a free download from the USGC website and provides a condensed version of the full reference guide.

4.1 Sustainable Sites

LEED NC has 100 possible points. Of these 100 points, the sustainable sites category has 26 points. Points can be earned for selecting sites that don't impact wetlands or other sensitive areas. Developing high density projects, including pedestrian access and public transportation are more opportunities for points. Stormwater quantity reduction and quality improvement, limiting heat island effects and reducing light pollution are also part of the sustainable sites area.

4.2 Water Efficiency

Water efficiency has 10 possible points. There are up to 4 points in landscaping for employing strategies such as using native plants. Two points are available for innovative wastewater technologies (reducing use of potable water for sewage conveyance). Four points are possible in water use reduction. Low flow faucets and toilets are common strategies for achieving these points.

4.3 Energy and Atmosphere

Energy and Atmosphere has the most points of any category with 35. It also is the category that promotes and requires the most integration in design. Like water efficiency, E&A points are gained for improving performance against a baseline. Building performance used the standard of ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers). Optimizing energy performance by 12% based on cost earns one point, with another point available for each 2% improvement, up to a total of 19 points for a building that is 48% better than the ASHRAE standard. Note that many large cities do not have strict building codes, so even achieving ASHRAE standards may require 10% or more improvement in performance.

Continuing with E&A, seven points are available by using on-site generated power, using photovoltaics, wind, micro-hydro or other strategies. Two points can be earned for enhanced commissioning. Commissioning is a pre-requisite, enhanced commissioning goes beyond basics and includes a review of the systems after 3 seasons of operation. Two points are available for early compliance with the Montreal Protocol and eliminating or significantly reducing ozone depleting refrigerants. Up to 3 points can be earned for on-going measurement and verification of energy consumption. Finally, up to 2 points can be earned by contracting to purchase green power, which is sustainable power generated by a third party.

4.4 Materials and Resources

Fourteen points are possible in the Materials and Resources area. Collection of recyclables is a prerequisite. Dedicated space must be set aside for occupants use to collect and store glass, plastics, paper and cardboard.

In a renovation project, reusing significant percentages of existing walls, floors and roof is worth up to 3 points. Another 1 point can be earned for reusing interior non-structural elements such as doors and ceiling systems. Inefficient systems such as windows can be excluded from this calculation so as not to penalize performance upgrades.

Construction and demolition waste makes up some 25% of all solid waste in the USA. Under LEED, 1 or 2 points can be earned by diverting 50% or 75% respectively of construction waste from landfills. Up to 2 more points can be earned by reusing materials such as cabinetry, bricks and decorative items.

Two points are available for using materials with recycled content and another 2 points for using materials that come from within 800 km of the site. Using rapidly renewable materials such as agrifiber, bamboo, linoleum and others that are obtained from annual crops is worth one point. Finally, one point can be earned by using wood that comes from well managed forests as certified by the Forest Stewardship Council.

4.5 Indoor Environmental Quality

Indoor environmental quality (IEQ) has 15 points. Two prerequisites are in this category: minimum indoor air quality and tobacco smoke control. Tobacco smoke is an example of something that is rapidly becoming a non-issue. Many states and companies, and all airports, now ban smoking inside buildings, so there is no smoke to control.

Monitoring CO_2 levels and outdoor air delivery in occupied spaces is one point. Increasing outdoor air delivery above ASHRAE standards is another point. A quality management plan during construction, limiting contamination of the permanent air handling systems, is 1 point. Air quality prior to occupancy, achieved by flushing the building about 1,000 times (4,250 cubic meters of air per square meter of floor area) is also 1 point.

Avoiding volatile organic chemicals (voc's) during construction by using low-emitting adhesives and sealants is worth 1 point, and using low-emitting paints and coatings is worth another 1 point. Avoiding voc's in permanent materials can earn 1 point for flooring and 1 point for non-formaldehyde resins in composite fiber products. Adequate exhaust to remove gases and chemicals and filtering air in the building is also worth one point.

In the IEQ category we also have 2 points for controllability of systems; one for providing controllable lighting and another for control of thermal comfort. Another point is available for designing the HVAC system to meet ASRHRAE standards for thermal comfort. One point can be earned by providing a permanent monitoring system and surveying occupants regarding thermal comfort.

Daylight and views round out the IEQ category. One point can be had for providing natural daylight to 75% of occupied spaces. One point can be earned by providing horizontal views of the outdoors in 90% of regularly occupied spaces.

Indoor environmental quality is possibly the least exploited in terms of marketing the advantages of green building. Improvements in worker productivity, reduced staff turnover, improved recruiting, enhanced recovery from illness and enhanced learning are just some of the potential benefits of improved environmental quality.

4.6 Innovation and Regional Priority

There are 6 points possible in the Innovation in Design (ID) category. This allows the designer and builder an opportunity to address an issue not otherwise covered by LEED, or to do an exemplary design in one of the existing areas. For example in the Materials Reuse credit there are 2 points available. Using 5% salvaged materials (based on cost) is 1 point. Using 10% salvaged materials is 2 points. If a project can achieve the next incremental threshold it can earn another ID point. In this example, using 15% salvaged materials would earn 2 points in materials reuse plus 1 point in the ID category. There is also one point for having a LEED accredited professional as a principal participant on the design team.

A new category from LEED NC version 2.2 to version 3 is Regional Priority. This provides incentive to recognize that different areas have different environmental priorities. In Rolla Missouri, earning 4 of the 6 points identified as regional priorities will earn a bonus point under regional priorities. The 6 areas identified for this rural city are:

site selection (avoiding prime farmland and wetlands), protecting or restoring habitat, reducing stormwater runoff impacts, using on-site renewable energy, reducing construction waste sent to landfills and using regionally manufactured materials.

4.7 Discussion of LEED

LEED has its proponents and opponents. On the positive side, LEED has raised awareness of Green Buildings. It also seems to be driving demand. The US Navy adopted LEED Silver-level performance as a minimum for new buildings. Similarly the US Department of the Interior, Environmental Protection Agency and others have adopted LEED standards for new and existing buildings. California and Connecticut, Kansas City and Dallas are just a few of the many states and cities that have adopted LEED for public buildings.

Some of the complaints about LEED focus on relative importance of points. In earlier versions there were equal points for installing a bicycle rack and shower as there were for cutting another 3.5% in energy use. There was also a lack of consideration for different regions of the country, some of which is addressed in the regional priorities section of LEED 3.0. However, there is still 1 point for using a white roof in the Heat Island category, even if the building is in a cold mountainous climate where a dark roof might actually save energy on an annual basis.

LEED 3.0 has addressed some of the concerns with earlier versions. In LEED 2.2, there were 5 points related to site selection that were unrelated to design issues, and 26 points was the lower limit for certification. In 3.0 there are up to 13 points that depend on site selection. LEED 3 requires 40 points for certification, so almost one-third of the points can be attained by selecting the right site. Encouraging a much earlier engagement in sustainability should help LEED to make a bigger impact.

LEED is not a building code. This makes it difficult to tie regulations to LEED. For one thing, a building can be de-certified, and this would create problems for local building authorities. Subjectivity in some of the points makes them difficult to enforce. However, because LEED is a driving force in the Green Building industry, standards and codes are evolving with LEED.

ASHRAE proposed standard 189 *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*, is being written to provide minimum requirements for the design of sustainable buildings to balance environmental responsibility, resource efficiency, occupant comfort and well-being, and community sensitivity. It is being developed in conjunction with the US Green Building Council and other interested parties and will codify much of LEED. ASHRAE 189 is planned to be written such that it can be included in building codes. It includes energy and water issues, and the committee is looking at requirements for sustainable sites, indoor air quality, and other areas covered by LEED.

Whether LEED and other initiatives have increased the market for sustainable buildings or not, there has been a marked increase in demand. Last year, 2008, the demand for green buildings was $12 billion US. By 2010, next year, the demand is forecast to be $60 billion [6]. As more green buildings come on line and more data about cost savings, increased productivity and other benefits becomes available the shift toward sustainability will only continue.

5. Education

To design and build sustainably, we need designers and constructors. There are few programs in engineering and architecture that don't include sustainability in the curriculum. The organization that accredits engineering programs in the US is ABET. Of the eleven criteria for that apply to all engineering disciplines, there are several that include or imply sustainability. Criterion c is "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" and criterion h is "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" (emphasis mine). Knowledge of contemporary issues and ethical responsibility are also mentioned and imply sustainable design. Students are very interested in learning as much as they can about green building. In addition there are competitions for undergraduates that focus on sustainability, including the Solar Decathlon.

6. The Solar Decathlon

The Solar Decathlon is a biannual competition sponsored by the US Department of Energy. The first competition in 2002 attracted 13 US teams and a team from Puerto Rico. The next competition was held in 2005 to give an extra year for organizers to make changes. In 2005 teams from Canada, Puerto Rico and Spain joined 15 US teams on the National Mall in Washington D.C. In 2007, a total of 20 teams representing the US, Puerto Rico, Spain, Canada and Germany competed. In October of 2009 20 teams will once again be on the Mall. Canada has two teams and Puerto Rico Spain and Germany are also represented. [7]

The objective of the Solar Decathlon is to design and build a house that can operate on the power it generates from the sun. Houses are limited to a roof footprint of 74.3 square meters. Solar collection can only be within this footprint. Photovoltaic systems supply electricity. Solar hot water systems are also allowed. Wind power is not an option, nor are ground source heat pumps due to the location.

In the early competitions, teams were generally a single university. 2009 features Team Alberta, Team Boston, Team Ontario/BC, Team California and Team Missouri. This reflects at least two facts. It is expensive to build a solar house and move it across the country or the ocean, and it takes a variety of backgrounds, in architecture, engineering, and management to design a functioning green solar powered house. Missouri University of Science and Technology has competed in every Solar Decathlon. The systems in the houses make them expensive to build and as mentioned, the logistics of moving a house add a lot to the budget. For planning purposes we budget $50 thousand US to transport the house and another $50 thousand US to take the team to Washington and feed and house them. Setting up the house, competing and removing the house requires nearly one month.

There are 10 contests in the Decathlon, and 1,000 points total. The points have changed over the years, and the weights of various categories have changed slightly. About half the points are subjective, such as architecture, and half are objective such as maintaining specified temperature and humidity levels. The contests are:

- Architecture — 100 points, holistic design, inspiration, architectural elements
- Market Viability — 100 points, liveability, buildability, marketability
- Engineering — 100 points, functionality, efficiency, innovation, reliability
- Lighting Design — 75 points, quality of electric and day lighting, ease of operation, flexibility, energy efficiency, integration
- Communications — 75 points, website, open house tours, newsletters
- Comfort Zone — 100 points, stable temperature (22.2C to 24.4C) and humidity level (40% to 55%)
- Hot Water — 100 points, adequacy of supply for showering and typical uses
- Appliances — 100 points, refrigerator, freezer, dishwasher and clothes washer capacity and efficiency
- Home Entertainment — 100 points, cooking and hosting neighbors, adequate light levels, operating a TV and computer
- Net Metering — 150 points, producing at least as much if not more energy than the competition uses

Net metering is a new contest. Previous teams had to use a storage scheme, typically lead acid batteries. An electric car could be driven to use up excess power and gain extra points. Two major complaints about the battery and car system were the danger of driving in Washington D.C. traffic and more significantly that energy balance was not a scoring category. The top teams in 2005 actually operated primarily on over-sized battery arrays that they charged ahead of time and ran down over the course of the competition. To avoid a battery Olympics in the future, organizers have made net-metering the highest scoring category.

7. Barriers to sustainability

There are technical issues to overcome, but some of the largest barriers to increased sustainable development are non-technical. We need more demonstrations of how green buildings save money, not just in operating costs, but in improved productivity and improved worker retention. More attention must be paid to life cycle costs. Lenders typically look at first cost, making it difficult to borrow more money for upgrades that will save money in operations. Codes and standards will also be required if we are to see the full benefit of green construction.

8. Conclusions

The United States must embrace sustainability in the built environment. Buildings are major users of energy and major sources of pollution. LEED and other initiatives are driving the market toward a more sustainable future, but challenges remain. On the bright side, universities are embracing the subject of sustainability through coursework and competitions such as the Solar Decathlon. There is much important work to be done in the design and construction industry to develop the growing impetus toward green construction.

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Sustainability of Buildings - Planning tools for the assessment of the sustainability building performance

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Abstract

To assess and certify the sustainable performance of buildings, standardized assessment and rating methods are necessary. These tools should contain a high level of detail and be as clear as possible and easy to understand for the user. There are already several international and European approaches to planning instruments for the assessment of the sustainable building performance of buildings, such as BREEAM (Building Research Establishment Environmental Assessment Method, GB), LEED (Leadership in Energy and Environmental Design, USA), SBTool (Sustainable Building Tool, World Green Council, international), LEnSE (Label for Environmental, Social and Economic Buildings, Europe) or DGNB (German Certificate for Sustainable Buildings, Germany) etc.. The paper will give an overview about international planning instruments for sustainable buildings, as well as a comparison of these assessment and rating methods.

Keywords: Certification of Buildings, Assessment of the Sustainability Building Performance, Assessment and rating methods, DGNB (German Certificate for Sustainable Buildings)

1. Introduction

The importance of building performance influencing sustainability is widely acknowledged and based on a lot of facts. The European building sector consumes about 50% of the natural resources, 40% of the energy consumption [1] and 16% of the water [2]. The continuously strong increase in the consumption of land of 120 hectares per day (Germany) and therefore also the accompanying increase in the CO_2 emissions are boosting the negative effects of buildings on the environment as well [3]. However, the importance of the construction sector is not manifested only in its impact on the environment. Also on the level of society considerations, construction practices affect core issues, such as accessibility, comfort, health, safety and security. In order to achieve sustainable buildings the development and application of planning instruments, methodologies and standards is very important. Especially for the documentation and assessment of buildings within the framework of a sustainable development, special tools and instruments must be required, which are containing relevant information for the planning process [4]. Therefore the paper will show the major important international assessment and rating tools, like LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method) and the DGNB (German Certificate for Sustainable Buildings) as well as the comparison of these assessment methods.

2. Planning tools for sustainable building

At an international level, a great variety of complex planning and assessment tools are presently available for sustainable architecture. These tools are addressing particular users, they are related to specific assessment objects, employ carefully selected methods, contain linkages to data bases and calculation methods (if required) and display results in different forms and levels of detail [5]. These tools are addressing particular users, they are related to specific assessment objects, employ carefully selected methods, contain linkages to data bases and calculation methods (if required) and display results in different forms and levels of detail [5].

These assessment tools were especially developed for the building industry, i.e. for planners (architects, civil engineers, environmental engineers, project developers), builders (building industry, facility management), financial institutions, society (research, citizens) and the political sector. Within the scope of sustainability assessment, however, appropriate tools need to include concrete, precisely formulated protection goals and leading indicators, which enable the planning team to recognize impacts and interrelations existing between social, economic, and ecologic dimensions and to adequately treat these in the process of planning and building, respectively. As a consequence, a great number of tools and aids designed to facilitate the assessment of the building sustainability are now available at the national and the international level. In the construction sector, this wide variety of available tools reflects the outcome of numerous complex tasks (like competitions, preliminary design, final design and construction documentation, assessment of completed buildings, etc.). The following list gives a survey of available tools and aids, which can be used to assess buildings [6]:

- Product declarations (EPD): building products and auxiliary building materials (e.g. environmental product declarations)
- Building components: functional units after installation
- Tendering aids: ecologically oriented technical specifications

- Energy performance certificates: Describing and assessing the energy efficiency of buildings
- Checklists
- Guidelines: Specification of objectives, principles and overall concepts (e.g. Guideline for Sustainable Building, issued by German Fed. Min. of Transport, Building, and Urban Affairs BMVBS)
- Tools for holistic planning and assessment (LCA, LCC): Interactive tools for decision-making (e.g. environmental performance evaluation: life-cycle costs)
- Building performance labels, building evaluation resp. certificates: building assessment (e.g. LEED, BREEAM, DGNB)

3. Assessment and certification systems for sustainable building

An important progress regarding sustainability assessment is based on the development of building labels and building certificates. These labels permit the comprehensive assessment of the quality of building and planning. In the early work phases of a building project they provide planners and builders with an assessment of the project, which may enable them to improve a building's sustainability performance already in the design phase [6]. Besides reducing and controlling a building's environmental impact, these certificates will also enhance competition by introducing a national label of quality [7]. Both building users and owners can rely on building performance certificates that were issued for completed buildings as a proof stating the sustainability performance of their building. The currently available evaluation tools cover a wide variety, ranging from very simple qualitative evaluation tools to precise tools that also include quantified data [6].

On the international level a great multitude of very different assessment methods is currently represented [8]. The British BREEAM label (the pioneer from the 90s) and the American LEED method have been internationally established. Due to its perfected marketing concept, this method has already been adapted for assessment by several countries, for instance LEED Canada, LEED India, LEED Emirates etc. The internationally oriented concept of the SBTool (formerly GBTool) provides a base or frame tool for new assessment methods, like the Austrian certificate TOTAL QUALITY (TQ) or the Spanish assessment tool VERDE [9]. To assess the sustainability performance of building also the German Certificate for Sustainable Buildings (DGNB) was developed last year.

The relative benefit achieved by the various assessment systems is vividly discussed among users and scientists. Quite understandably, no consensus on the 'best method' has been reached because comparability is not the aim of these applications and is not given in many cases. From a planner's and architect's point of view there are countless ways to achieve the desired effect and there are many ways to measure and evaluate the generated effect for demonstration to investors, owners and users of buildings [10].

To ensure the comparability of the various assessment labels in future, international and European bodies have begun to develop requirements and standards for the assessment of sustainable buildings. These standards, which are still in their developing stages, are to provide a uniform calculation strategy or methodology.

At an international level, standardization is to be continued with international standard ISO TC59SC17: Sustainability in Building Construction (currently still under preparation). At the European level, the document prepared by CEN/ TC 350: Sustainability of construction works – Framework for assessment of buildings (to be completed) will be authoritative.

Assessment label	**Country**	**Derived from**
BREEAM (Building Research Establishment Environmental Assessment Method)	UK	
CASBEE (Comprehensive Assessment System for Building Environmental Efficiency)	Japan	
Green Star NZ (Green Building Council of New Zealand)	New Zealand	
Green Star (Green Building Council of Australia)	Australia	
NABERS (National Australian Built Environment Rating System)	Australia	
LEED (Leadership in Energy and Environmental Design)	Canada	
LEED Canada	Canada	
LEED Emirates	Emirates	
GOBAS	China	
DGNB (German Certificate for Sustainable Buildings)	Germany	
HQE (Haute Qualité Environnementale)	France	

Minergie	Switzerland	
SBTool (Sustainable Building Tool)	International	(GBTool)
Protocollo Itaca	Italy	(GBTool)
TQ (Total Quality)	Austria	(GBTool)
VERDE	Spain	(GBTool)
LenSE	Europe	
etc.		

Fig. 1. *Labels and certificates for the assessment of the sustainability of buildings*

4. Comparison of the assessment methods

Many assessment systems are based on other existing systems, either advancing these or adapting them to country-specific requirements. For instance, LEED and the Australian Green Star method made use of the experience gained with the pioneer method BREEAM (first assessment method), the Japanese CASBEE label utilized the long-standing experience of LEED, BREEAM and the SBTool, and the German label of quality integrated the experience of the predecessors.

In general, the assessment methods can be assigned to two categories, distinguishing assessment typologies of the first and second generation. The assessment methods of the first generation include those tools which were the first systems to be developed in the 1990s, attributing priority to evaluating the "green" or environmental and energy-efficient building performance criteria (like BREEAM, LEED or CASBEE), i.e. featuring the Green-building approach. Second-generation assessment methods include those tools which do not only consider environmental building criteria but the overall performance of the entire construction, namely also economic, socio-cultural and technical aspects or aspects related to site and process quality (Sustainable-building approach). These systems were mainly developed in the last few years. They are based on the experience gained with the first-generation tools, but some of them are still in their test phase. This category is represented by the SBTool, the European LEnSe method or the new German DGNB certificate for sustainable buildings, which was introduced in 2008 (the first pilot phases were started in September of 2008).

	BREEAM	LEED	DGBN
Ecological aspects	• Water	• Water Efficiency	• Resource utilization and waste accumulation
	• Materials	• Materials and Resources	

	• Pollution		• Efforts on the global and local environment
Energy efficiency aspects	• Energy	• Energy and Atmosphere	• Resource utilization and waste accumulation* • Technical Quality*
Comfort aspects	• Health and Well-being	• Indoor Environmental Quality	• Health, thermal comfort and user satisfaction
Economic aspects			• Life-cycle costs • Value performance
Socio-cultural and functional aspects			• Functionality
		• Innovation and Design Process	• Design Quality
Technical aspects			• Technical Quality*
Process aspects	• Management		• Planning Quality • Construction Quality • Operating Quality
Site aspects	• Transport • Land Use & Ecology	• Sustainable Sites	• Site Quality

* multiple listings

Fig. 2. *Comparison of the contents of BREEAM, LEED and DGNB*

Differing cultural, political, and climatic starting conditions complicate the comparability of these systems. For instance, the LEED system is based on American standards like ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), whereas the DGNB label of quality is based on the German Energy Saving Ordinance (EnEV). Further, the above-mentioned methods differ structurally. Apart from the LEED point system, the methods proposed by BREEAM and DGNB are featuring a weighted approach, i.e. the individual criteria of assessment have different relations.

When comparing different systems to one another, the assessment criteria used in these systems in most cases cannot be clearly attributed to specified aspects. From the comparison of the BREEAM, LEED and DGNB methods a classification into the following aspects resulted, namely: ecological aspects, energy efficiency aspects, comfort aspects, economic, socio-cultural and functional aspects, technical (building services), construction process and site-related aspects (see Fig. 2). Several criteria, like 'technical quality' (DGNB), cannot be clearly assigned to the sub-aspects defined here, which is why they have been categorized twice, as aspects related to energy-efficiency and to building services.

To sum it up it can be said that the assessment methods were developed to suit the special needs of their respective countries of origin, like LEED for North-American conditions, BREEAM for the situation in Great Britain and DGNB for applications in Germany. Due to this fact, the international application and the comparability of these methods are possible to a limited extent only (see the international marketing activities for LEED), because the methods of assessment do not consider the country-specific conditions like politics, culture, and climate. To ensure the quality of the different methods of assessment also in future, it is absolutely essential to enhance feedback and transfer of knowledge among these systems.

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Sustainable housing – how facility services of the low-energy building concept can support sustainable housing and resident´s sustainable behavior

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Abstract

Purpose

The purpose of this paper is to examine the role of the resident and housing services in the implementation of the new sustainable concepts in the housing sector. The users of the spaces, the residents and the consumers of the facility services are playing the key role in the intelligent use of the new sustainable infrastructure and innovations. The residents' willingness or unwillingness to adapt and skills to use the sustainable concepts can multiply or invalidate the benefits of the sustainable development of the infrastructure.

Design/methodology/approach

The research applies theories of sustainability and facility (housing) management. The objective is to describe how facilities services in housing sector can support the intelligent use of new sustainable infrastructure and sustainable housing and resident's sustainable behavior. The research reviews the former research findings about sustainable housing and environmental behavior. The research is exploratory and is conducted by an empirical study with interviews and walk through observations.

Findings

The results of this research assign that providing sustainable housing and supporting tangible environmental friendly acts requires integrated service solution and observation of the residents´ demands and skills. Facility services ans sustainable supply chain management connected to the low-energy building concept can be a successful element of providing sustainable housing.

Originality/value

The findings of this study indicate that it is not enough to provide sustainable infrastructure and low-energy buildings if they are not usable and motivate individuals to sustainable behavior.

Keywords

Sustainable housing, low-energy building, resident, sustainable infrastructure, facility services

1. Introduction

Sustainable housing includes three perspectives: social, environmental and economical. The social perspective includes aspects like universally designed premises as well as safe and secure in living. Environmental perspective is about efficient resources in waste, water and energy. Thirdly economical aspects are about cost-efficient initially and over life cycle of the built entities. However the so called triple bottom line needs also a perspective of user – how the individual user, resident is using the sustainable solutions and how it can be supported.

This article is based on the project which is focusing on the role of user in sustainable housing. The aim of the project is to find out how the sustainable, often technical solutions can be usable in housing sector. Additionally the intention is to map what kind of support service could be provided for the user in order to help the sustainable behavior in daily living in low energy houses and apartments. This article introduces the present situation of sustainable housing. It also discusses on the growing significance of the behavior of the user (the resident). Building sector seeks to build more environmental friendly housing partly due to the new regulations and norms but partly because of the requirements of the markets. The results presented in this article indicate that the motivation of the user can be increased by information and guidance how to use the sustainable built solutions. The variety of sustainable housing services can support users' sustainable behavior and there are different methods to develop these services.

2. Sustainability and sustainable housing

In common discussion sustainability has almost as many definitions as there are stakeholders. According to Priemus (2004) `sustainable' seems to mean everything in the broad literature about sustainable housing. It is about ecology and the environment, but it is more than technology: it is also about social cohesion, community sustainability, citizen participation, and lifestyles. Sustainability includes profit, people, and planet at the same time; it reminds in general the happiness. In this article the definition of sustainability is applied from Brundtland (1987): sustainable development "is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Presumably, the central consideration of the Brundtland (1987) is whether the planet is capable of sustaining its inhabitants. However sustainable development requires changes relative to the current situation; sustainable development has characteristics of an innovation process (Gerlach 2000).

The main focus in this article is on the ecological and environmental perspective of sustainable housing and how individual user can adapt to them in housing sector. Nevertheless the other two perspectives, the social and the economical aspects of sustainability are considered. Although the ecological dimension of sustainability is more studied and perhaps easier to approach than the other two dimensions. All three dimensions are needed to the sustainable development, they are linked with each other and they intermesh in the daily life of sustainable housing.

In the literature sustainable housing is defined in various ways too. One comprehensive definition is given by Priemus (2003): He defines sustainable housing as “housing with a minimum of negative environmental impacts in terms of climate change (greenhouse effect); the quality of air, water, and soil; noise; stench; the stock of nonrenewable materials; and biodiversity”. In this article the definition of sustainable housing is inspired by definition of Premius, which however does not include the impact of the inhabitant. Next to the minimum of negative environmental impacts, it is important to include housing that supports the social well-being and the feeling of community into the sustainable housing. Together these perspectives preserve the economical value.

The measuring criteria of sustainable can be demonstrated by ten different set of examples criteria sorted into the three perspectives. Criteria connected mainly to the environmental perspective are energy consumption, logistic accessibility, and healthy materials. Criteria connected to the social sustainability are community feeling, safe neighborhood, stress free environment and suitability to the existing environment. Criteria connected to the economical sustainability are life cycle costs, recycling and renewable materials, two latter are also connected to environmental sustainability. (See figure 1) These suggestive criteria are incommensurable and they are not comparable. But based on these criteria we can estimate and explain the sustainability of a housing project during the whole life cycle.

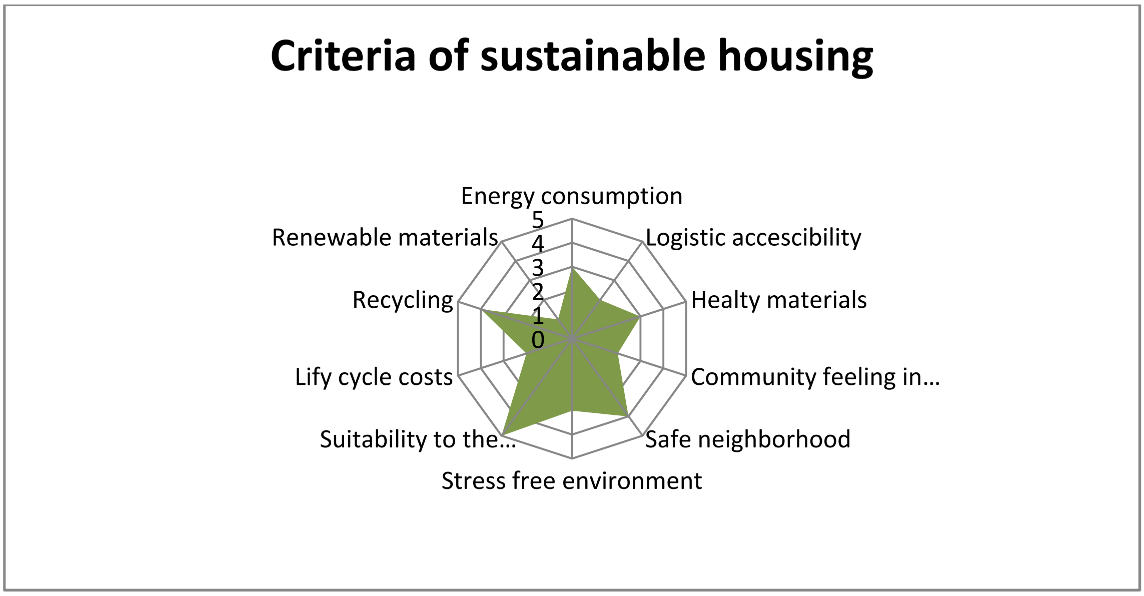

Figure 1 ***Criteria of sustainable housing***

To sum up the criteria of sustainable housing are interest of many stakeholders. The construction project and the outcome of it are the interest of design and construction both in the scale of infrastructure and the single site. An important characteristic of building projects is that every project consists of a combination of semi-finished products, which are assembled at the building site. Therefore, the environmental burden (the eco-costs) of a building in the production phase can be considered as consisting of the eco-costs of those semi-finished products plus the eco-costs of the assembling activities (including all additional works like preparation works, building site facilities and management). The urban planning and areal development as well as society have their interests in part of the dimensions. The investors and owners focus on cost efficiency figures. The maintenance, facilities services and use of the buildings has their effect to some criteria of sustainable housing. In the operating phase, the most important factors of ecological burden are the energy demand and the maintenance of the building in use. In order to keep user or resident on focus, we will next identify principles of individual sustainable behavior in order to understand how they can be supported.

Residents motivation towards sustainable behaviour

Grob (1995) has studied the multivariate relationship between environmental attitudes and pro-environmental behavior. In two studies a structural model linking environmental awareness, emotions, personal-philosophical values, perceived control and behavior was proposed and tested. The main questions investigated were (a) whether, to what extent, and in which constellation personal belief systems affect environmental behavior, and (b) the generalizability of the model from two known groups. The strongest effect on environmental behavior stemmed from personal-philosophical values and emotions. No effects on environmental behavior stemming from factual knowledge were found. Thirty-nine per cent of the variance in environmental behavior was explained by the attitudinal components.

The study on motivations towards environmental protective behaviour has done by Robert B. Cialdini (2003). He studied public communication and advertisements against littering and harmful behaviour in a national park. He recognised two type of norms; *injunctive norms* (involving perceptions of which behaviors are typically approved or disapproved) and *descriptive norms* (involving perceptions of which behaviors are typically performed). Much research indicates that both kinds of norms motivate human action; people tend to do what is socially approved as well as what is popular. The wisdom of setting these two kinds of motivations in line with (rather than in opposition to) one another within a communication has direct implications for the development of pro-environmental messages.

Public service communicators should avoid the tendency to send the normatively muddled message that a targeted activity is socially disapproved but widespread. One example could be an advertisement trying to attract people to leave their cars home and instead to use the public transportation by showing the rush on the highways; an effect of these kind of advertisement is a though that why should I take the bus when everybody else a driving their cars. Norm based persuasive communications are likely to have their best effects when communicators align descriptive and injunctive normative messages to work in tandem rather than in competition with one another. Such a line of attack unites the power of two independent sources of normative motivation and can provide a highly successful approach to social influence. (Cialdini 2003)

Cialdini and his colleagues (2003) conducted also a study in which college students were viewed three recycling advertisements and rated their impact along several relevant dimensions. That study was designed to determine whether the advertisements had the intended effect of conveying to viewers that recycling was prevalent (descriptive norm) and approved (injunctive norm), whether these perceived norms influenced viewers' intentions to recycle, and whether the two types of norms operated similarly or differently to affect recycling intentions. A statistical analysis of the results indicated that both normative and non normative factors influenced the intent to recycle. The finding that non normative factors (prior attitude, new information, humor) had causal impact is not incompatible with our theoretical position, as one certainly would not claim that normative factors are the only motivators of human responding. At the same time, it is encouraging from theoretical perspective that both injunctive and descriptive normative information significantly influenced recycling intentions. That is, as a result of viewing the ads, the more participants came to believe that recycling was (a) approved and (b) prevalent, the more they planned to recycle in the future. It is noteworthy that, despite a strong correlation (r= .79) between participants' perceptions of the existing prevalence and approval of recycling, these two sources of motivation had independent effects on recycling intentions. (Cialdini 2003).

Poortinga et al. (2004) have identified the role of values in the field of household energy use. The seven value dimensions concerning quality of life values and general and specific environmental concern contributed significantly to the explanation of policy support for government regulation and for market strategies aimed at managing environmental problems as well as to the explanation of the acceptability of specific home and transport energy-saving measures. In line with earlier research, home and transport energy use were especially related to socio demographic variables like income and household size. These results show that it is relevant to distinguish between different measures of environmental impact and different types of environmental intent. Moreover, the results suggest that using only attitudinal variables, such as values, may be too limited to explain all types of environmental behavior.

Derijke and Uitzinger (2006) have found out are that if the residents use the technology in a way not indented by the designer, the environmental benefits designed for the in the building stage may be partially lost during the use. They show in their case study from Netherlands that the most important factors for residents in the decision to buy a house were price, appearance, size and the fact that it is a new estate. The fact that the house was sustainable was much less important. Their case study indicates that environmental issues were more important for residents that participated in the building process. They argue that sustainable systems in residences should be designed in such a way that environmentally-preferred behaviour is also the most logical and easiest accomplish. Otherwise, the system should be designed in such a way that it is indifferent to residential behaviour. (Derijke and Uitzinger 2006)

In everyday life it is very important that and effective that residents have agreed with goal-setting for example in energy consumption. But a goal-setting alone is not sufficient in order to change the behaviour as for sustainable energy consumption. A frequent and specific feedback is a successful means of encouraging energy conservation when users are first encouraged to set a goal. (McCalley and Midden 2006)

The research results explain that the environmental behaviour of individual, residents has its linkage to attitudes, values, normative and descriptive information as well as effect to the choices people make. Additionally the logic and easiness in use of sustainable solutions have been pointed out. In the following section we take a look to services which could support these elements of the behaviour.

Maintenance and facility services in sustainable housing

Lorek and Spangenberg (2001) have identified areas of consumption in which private households can make significant contributions to environmental sustainability, and presented a transparent and comprehensive set of indicators for them. Based on their analysis, three consumption clusters were identified as priority fields for action by households: construction and housing, food/nutrition and transport (in this order). All other consumption clusters can be considered environmentally marginal, providing combined saving potentials of less than 10% of the total resource consumption. Halme et al. (2004) claim that the discussion about ‘sustainable services’ or ‘sustainable product–service systems’ tends to emphasize the eco-efficiency perspective, rather than explicitly capture all sustainability aspects. Social or socioeconomic considerations are often forgotten or by-passed without scrutiny. They argue that there is the need for a concept of sustainable services in which the social sustainability aspect is also recognized with equal attention. Since a major part of private consumption occurs in the household context-living at home and moving to and from it—they have put forth the concept of sustainable home services. Households alone have a limited capacity to influence their consumption choices, because other actors set the frame. For this reason, institutional arrangements for making services easily available to households are worth to develop. It appears that housing organizations have a central role in the alternative option for organizing the supply of service provision. They are involved in five of the seven alternative ways of supplying services that could be identified. The role of the housing organization can vary from direct supply to lighter forms, such as cooperative arrangements with external service providers, or resident involvement.

Mentzer (2001) defines supply chain as a set of three or more companies directly linked one or more of the upstream and downstream flows of products, services, finances, and information from a source to a customer. Based on notions above the sustainable housing services could create a supply chain, which could provide support for the residence in environmental actions. Facility services are focused to the maintenance of the real estate. The objective of the maintenance of the real estate is to preserve the condition, the value and the properties of the real estate. Facility service can be divided into the real estate services and user services. Traditionally they are discussed in context of offices, hospitals and larger space segments. (Puhto et al. 2001). However, maintenance of the technical systems, maintenance management, cleaning, maintenance of outdoor areas and waste management as parts of the housing services can be understood as part of facilities services in housing context.

In the commercial property environment facility services are normally organized based on three different relationship types; arm´s length relation, operational partnering and strategic partnering. Strategic partnering seems to be the most uncommon relationship type in the FM services context. It is usually used by real estate investment companies which are buying a wide range of management services. In general, both arm’s length relations and operational partnering are used more widely in managing outsourced FM services. (Lehtonen 2006 p. 32-33)

Traditionally in the housing environment most of the facility services are produced as in-house production. The larger customer groups for the residential services come from some special groups as elderly, student and from physically handicapped groups. Many of the services are made by residents without even noticing the possibility to other options. But based on future consumer trends one can assume in the future in facility services will expand to the residential context (Heinonen and Ratvio 2004). We assume that in the future it will be more normal and culturally acceptable to consume services instead of producing them by oneself. It is presumably that service providers from the commercial property environment will enlarge their services to residential customers in the near future. Nousiainen and Junnila (2006) state that end-user-energy-management services are needed in facilities management. Although the user behavior is more challenging to manage than pure technology, it can be quite profitable.

3. Method and empirical findings

As research methods in this study the semi structured theme interviews were used in order to investigate the possibilities for future sustainable housing services. Additionally modified customer journey analyze connected to walk through observation in private housing in order to find out the data about usability of sustainable solutions. To analyze the theme interviews and observation discussions the selective coding (Strauss and Corbin 1998) was utilized and the categories based on the central category were formed in order to identify how to support sustainable housing and living. Subcategories were found and they had linkages like resident´s motives, available services and desired services to central category.

Three different semi-structured theme interviews were accomplished on spring 2009. Their length varied from an hour to an hour and half. The objective was to find interviewees with three perspectives to sustainable housing: providing, using and managing sustainable housing. The sample included one consultant and provider of sustainable housing, one future resident in a co-planned sustainable apartment building in the middle of capital area and a chief executive of a large building manager company. All the interviewees were strongly motivated to develop sustainable housing. Target was to clarify the motivations and role of support services in sustainable housing.

Customer journey mapping has its roots in the corporate sector and market research. It is a visual, process-oriented method for conceptualising and structuring people's experiences. It provides a map of the interactions and emotions that take place, and can help an organization provide its customers with the experience it wants them to have. (Nenonen et al. 2008)

In this study we modified the customer journey mapping to be adequate to analyze the resident´s experience. The experience of living in a sustainable house is composed of several independent actions. These actions require from the resident knowledge that we cannot assume that he or she possess spontaneously. The customer journey map discusses the residential life as a journey with different action points from arrival to home, to spending time at home and again to leaving home. By using customer journey map one can analyze these action points and study what happens in one specific point from the perspective of the resident.

The important elements of the method are to identify the steps of the journey, different experiences and different interfaces effecting to the experiences in each phase of the journey. This formed a basis for the observation matrix. Customer journey is a walkthrough observation and they were conducted in two block of flats. The observations were conducted through the journey from outside to apartments with the emphasis also to public places like corridors, hallways etc. Additionally interviews were conducted for the residents. The main interest was to observe the interfaces, which link users to sustainable activities like recycling, energy saving etc.

4. Results

The results of the interviews and walk through observations include two perspectives: the resident´s sustainable behaviour and the characteristics of sustainable housing services. To reach the objective to support residents' behaviour towards sustainable actions motivation is an essential factor. Successful motivation needs four fundamental elements:

1) Relevant information about possibilities and ways to use environmental technical solutions
2) Delivering of information on crucial moment when the resident is acting in environmental friendly way – constant feedback of actions is also important
3) Social model example – the sense of sustainable community strengthens the individual actions
4) Mandatory norms.

In order to make the resident´s sustainable behaviour easier variety of services could support his or her sustainable actions and decisions. One can classify three perspectives which are success factors for developing sustainable housing services:

1) Understanding the role of service provider from assuring the usability to collaboration with other service providers from different branches e.g. logistics and nutrition
2) Understanding the role of user in sustainable housing services from user to collaborator and from routine actions to new behaviour and learning
3) Understanding the element of service as a product, service or experience. (See figure 2)

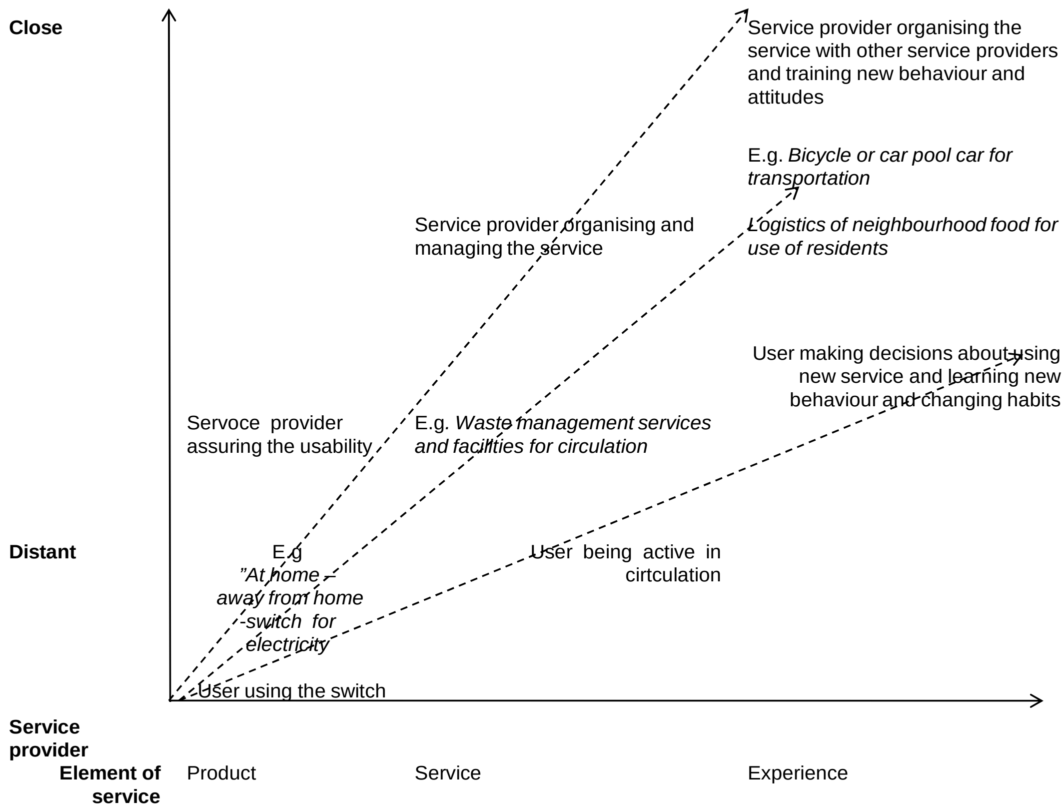

Figure 2 ***the perspectives for sustainable housing services***

In order to make the resident´s sustainable behaviour easier the variety of services could support his or her sustainable actions and decisions. According to the interviews only marginal amount of residents change their behaviour if the environment, where they live, does not support sustainable behaviour or even if the solutions are such that they make the environmental actions difficult. Observations indicate that not all the solutions were designed from the perspective of daily use. .

The daily journey in housing context include technical solutions, which support sustainability but might not be on the residents’ level of knowledge. One example is the energy consumption. It ws mentioned frequently that users would like to save the energy if they could be sure that they are doing the right decision and their actions has an impact. The concrete example is energy saving lamps, LED-lamps and traditional lamps. The driver for developing supportive services is to free the customer not to think about technical energy solutions but instead get assurance that the action taken is significant. Another example is the recycling; easier it is more resident are willing to do it.

In order to achieve environmental impact the scale of solutions varies from technical solutions in construction phase to constant management of services and experiences. The collaboration and co-creation is important when aiming to reduce the environmental impact by services and behaviour. The success of sustainable housing services depends on sustainable support service chain and its management. The sustainability in services can increase the sustainability in behaviour.

5. Conclusions

The development of sustainable housing services requires in the future more specific guidelines and alternatives for producing the services in collaboration with residents. Additionally it is not enough to concentrate only to the environmental dimension of the sustainability in the future. The significance of the impact of the resident´s behaviour grows more and more by the lifecycle of the housing. The design and planning phase have consequences to sustainable use and maintain of the residence. In the using phase the motivation of the resident is improved by adequate information at the right time, by the social role models and norms. The achieved motivation towards sustainable behaviour can be demolish with physical barriers and unusable, difficult interfaces.

Supply chain of sustainable housing services can give strong support to the resident´s sustainable behaviour. In order to provide more relevant, attractive and desired housing services it is important to understand that residential experience is based on continuous journey. Customer journey mapping follows the steps of the residential everyday life and shows the discontinuity points and critical moments where the resident needs assistance to behave sustainable way. By evaluating these critical moments service provider can find potentials for service design development. In the future it is presumable that service providers from offices and other space segments will expand their services to residential housing. In that case carefully service design is a key element for success.

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Analysis Tool for an Integrated Lifecycle Assessment of Industrial Facilities

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Abstract

From 2005 until 2008 the Institute for Building Materials, Concrete Construction and Fire Protection (iBMB) of the Technische Universität Braunschweig participated in the research program “Lifecycle Engineering for Industrial Facilities” supported by the Deutsche Bundesstiftung Umwelt (DBU). In the project, an interdisciplinary team of experts from industry, research and investors were cooperating.

The main ambition of the research project was the development of a software tool (LCE-Tool) which allows the user to perform an integrated analysis of a planned industrial facility, taking into account ecological, economical and social aspects during the whole service life.

For residential buildings and administrative buildings there are already some useful approaches available for an integrated analysis under ecological and economical aspects. However, for the industrial sector, which represents nearly 40 percent of the resources consumed by the building industry, no valuable analysis tool for the integrated assessment of the sustainability is existing.

Such an instrument was developed by the project mentioned above. This so-called LCE-Tool enables the user to perform a lifecycle analysis including a comparison between different design options of the planned industrial facility. The results are shown comprehensibly in graphics and charts. The tool is based on a database of construction options, factory technology and other criteria.

Keywords: lifecycle assessment, integrated analysis, industrial facilities, software tool.

1 Introduction

1.1 Project Aims

Nowadays energy efficiency, rising energy costs and climate changes are some of the issues which are discussed in our society and economic systems. Discussions make clear that solutions need interdisciplinary work. An integrated lifecycle analysis considering the topics ecology, economy and social aspects in balance may offer a suited solution (see fig. 1). In Germany such procedure is considered more and more. In 2001 the Bundesministerium für Verkehr, Bau und Stadtentwicklung (BMVBS) published the "Leitfaden Nachhaltiges Bauen" [1] to bring the integrated lifecycle analysis into practice. Since then a benchmarking comprising life cycle principles is required for administrative buildings. For residential buildings and administrative buildings there are already some useful approaches existing. For industrial facilities only a few helpful approaches for integrated lifecycle analyses are existing, although in this sector the functionality, the mutability, the estimation of the service life and the cost-effectiveness under life cycle cost aspects are the knock-out criteria. Usually the operating life of industrial facilities is briefer than of residential buildings, although the material input per unit is two or three times higher. Because of this the choice of the construction method and of the construction materials obtains a substantial significance.

Based on this the group "Wolfsburger Industrie Netzwerk - Life Cycle Engineering" (WIN-LCE) was founded in 2002. The project was promoted by the Deutsche Bundesstiftung Umwelt (DBU) from 2005 to 2008. The main aim was the development of a computer-based tool, the so-called LCE-Tool. This LCE-Tool enables the user to analyse and to compare different construction solutions of industrial facilities regarding ecological, economical and social criteria. The LCE-Tool was developed, designed and validated during the project and was implemented into practice after the validation in 2008.

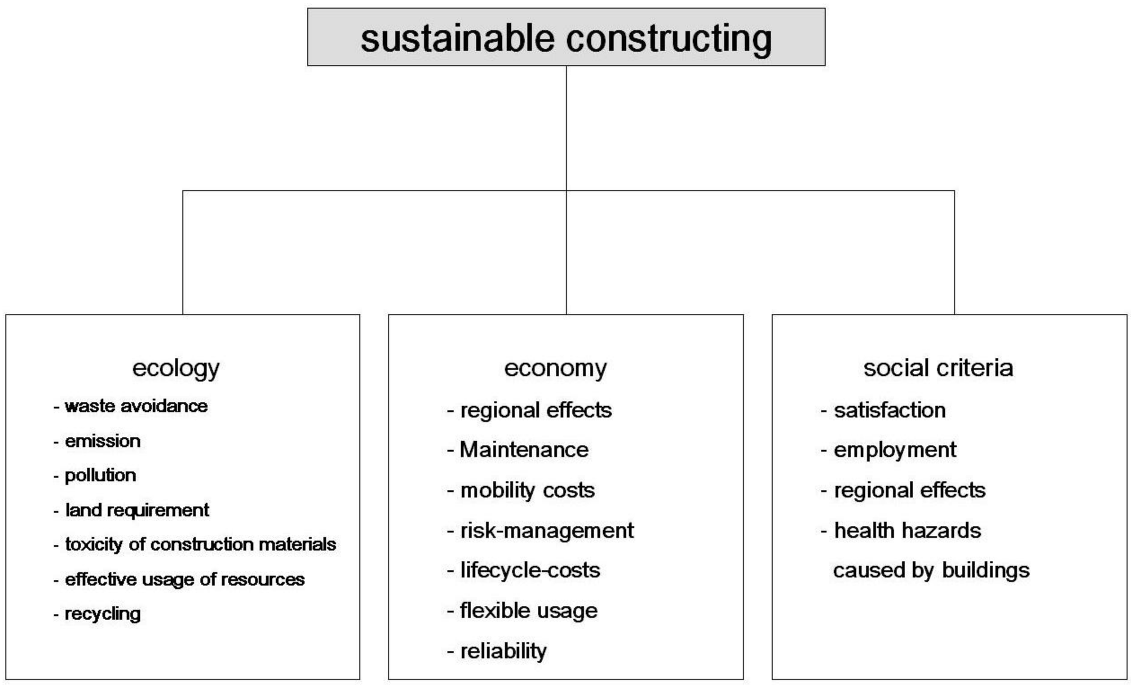

Figure 1. *Three pillars of sustainability*

1.2 Project Organisation

Mostly the design of industrial facilities is characterized by a leak of coordination between involved expert planners. A synchronized coordination between layout planning, facility planning, facility management and urban design taking economical, ecological, social and technical aspects into account is uncommon. Usually all these processes are handled more or less independent from each other so that neither an ecological nor an economical optimisation may be achieved. This common practice often leads to uneconomic facility layouts and planning.

The project WIN-LCE starts off at this point. The integration of planners and operators of industrial facilities in the development of the LCE-Tool guarantees the consideration and cross linking of all planning processes even for the manufacturing equipment, the building and the integration into the environment. The participants of the project are originating from different domains from practice and research. With the integration of planners, constructors and users of industrial facilities in the research project practical solutions have been found. The solutions were especially developed for small and medium sized businesses units.

The project was organized in five interacting working groups for the topics layout planning, facility planning, facility management, urban design and software development (see fig. 2).

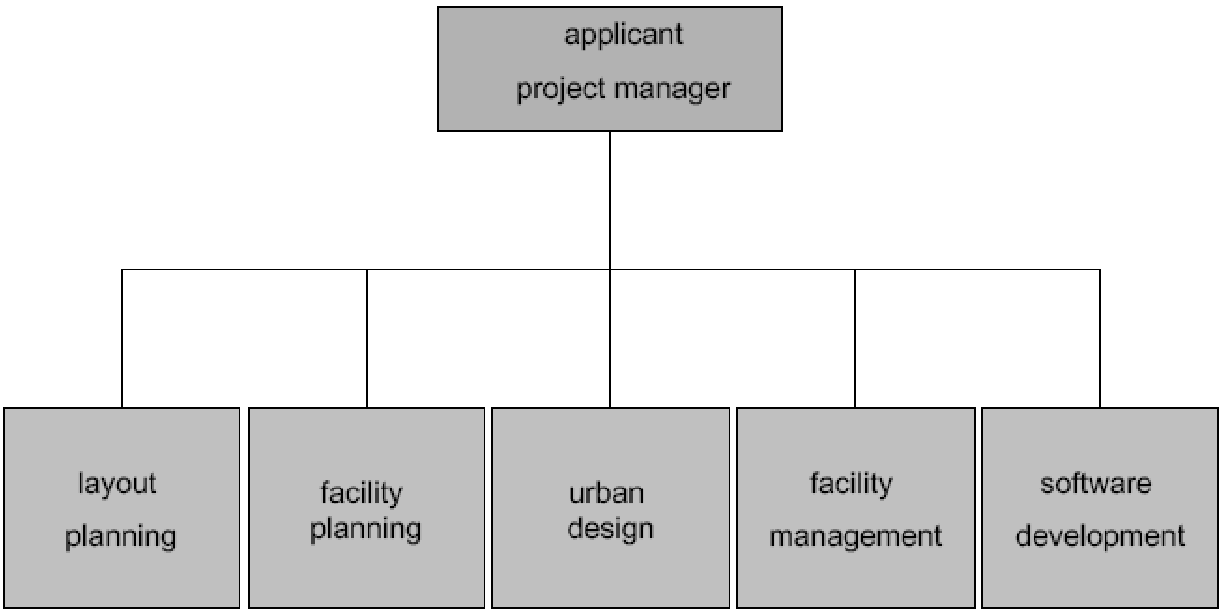

Figure 2. *Project structure*

2 Working Groups

2.1 Layout planning

The analyzed topics were the demands of the layout on the machinery and equipment, transportation and logistic corresponding to the building. In addition the influence of the structural shape, the technical equipment, the reuse of process heat and the over-all energy efficiency were analyzed. Another important aspect is the flow of goods, people, information, waste and media. The flow of goods is a main demand on the design of industrial facilities. So the placement of the couple points e.g. ramps and gates for incoming and outgoing goods is essential for a functional workflow. The coupling of the production area with the office and social area could be helpful for a communicative facility concept.

Another strategic goal is the mutability of the manufacturing systems and of the facility. The determination of the mutability and the elimination of deficits define the appearance of a company. Flexible customization of non-effective facilities are indispensable in dynamic and complex ambient conditions. Although the mutability is a main aspect of competitiveness in the future, general and comprehensive methods for a benchmarking are not available.

The development of a decision-supporting item in order to enhance the energy efficiency of industrial facilities was another topic. Important cognitions are relevant influencing factors on the total energy efficiency particularly the tasks of integrating regenerative energy production in the hull of the facility. In the project the potential of reusing the process heat was worked out.

One of the main aspects to save energy is the choice of a energy efficient construction form of the facility. Best construction principles are:

- a quadratic layout is better than an elongate or an angled layout
- a single floor construction is less compact than a building with two floors with the same effective area
- minor heights between floors
- avoiding contorted building hulls

2.2 Facility planning

The group facility planning developed the database of the LCE-Tool. Several existing buildings, so called reference buildings, were analyzed and the main data e. g. the effective area, construction costs and construction principles were generated. The data were generated by help of the software LEGEP [2] which was developed for an economic and ecologic benchmarking of residential and public buildings. For an analysis of industrial facilities typical construction materials and construction methods had to be supplemented to LEGEP.

The four references buildings were:

- a typical production facility of the automotive supply industry
- a facility with high ecological standard (equal-zero-emission facility)
- a high standard production facility (clean room facility)
- a double storey assembling factory (automotive industry)

By analyzing these reference buildings the data base was generated, combining the materials of the supporting structure, the span widths, the external construction (walls), the roof construction and the materials of interior walls. Figure 3 shows all possible combinations regarded for the first version of the LCE-Tool.

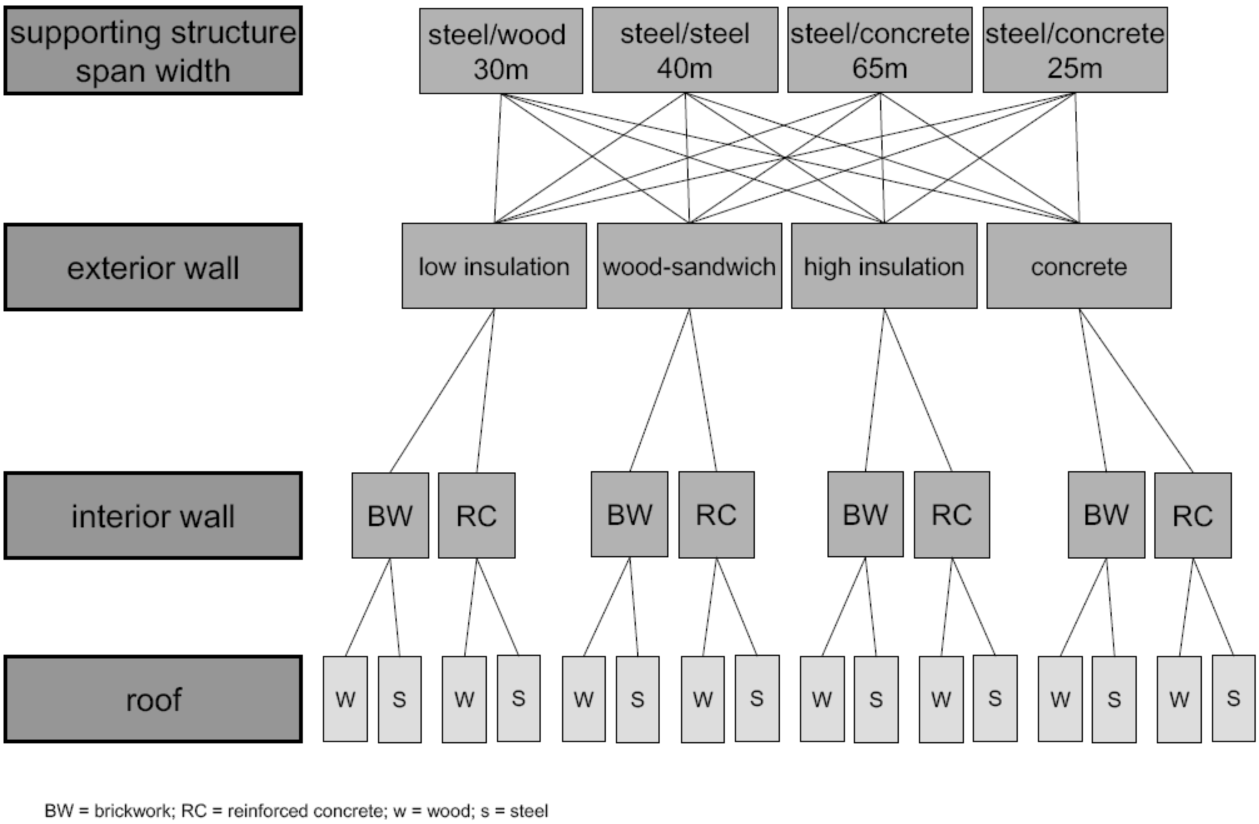

Figure 3. *Data base of regarded structures*

During the validation phase two more existing industrial facilities were examined and the data-base was completed. Furthermore all calculated cost rates were revised in order to expand the applicability.

Another aim was the implementation of deconstruction, recycling and reuse of facilities. This was performed by implementing information on the waste masses and the environmental impacts of a total demolition.

2.3 Facility management

The process flow chart of facility management is shown in figure 4. All possible cost sources during the life-cycle should be taken into account in the LCE-Tool. If all internal or external costs are considered, the investor can check methods to optimize his planning at a very early stage. Generally it can be noticed that the overhead costs are irrelevant compared to the manufacturing costs. During the project a simplified method of calculation was developed. This calculation is based on the German “Energieeinsparverordnung” (ENEV) from 2007 [3] and the experience from several existing industrial facilities. As a result the LCE-Tool calculation provided usable results for traditional constructions. For constructions with special technologies e. g. a block heating stations or thermal heat pumps the results differ from the authentic results.

The reuse of process heat was investigated too. The problem is the variance between the several production areas where the heat is generated and when thermal energy is needed for heating purpose. To keep the evaluation as easy as possible the calculation process was limited to a reduced over-all energy demand if a reuse of process heat is possible. For a more specific examination a special planning is needed. A general finding is that the heating energy costs are substantially less than the production energy costs.

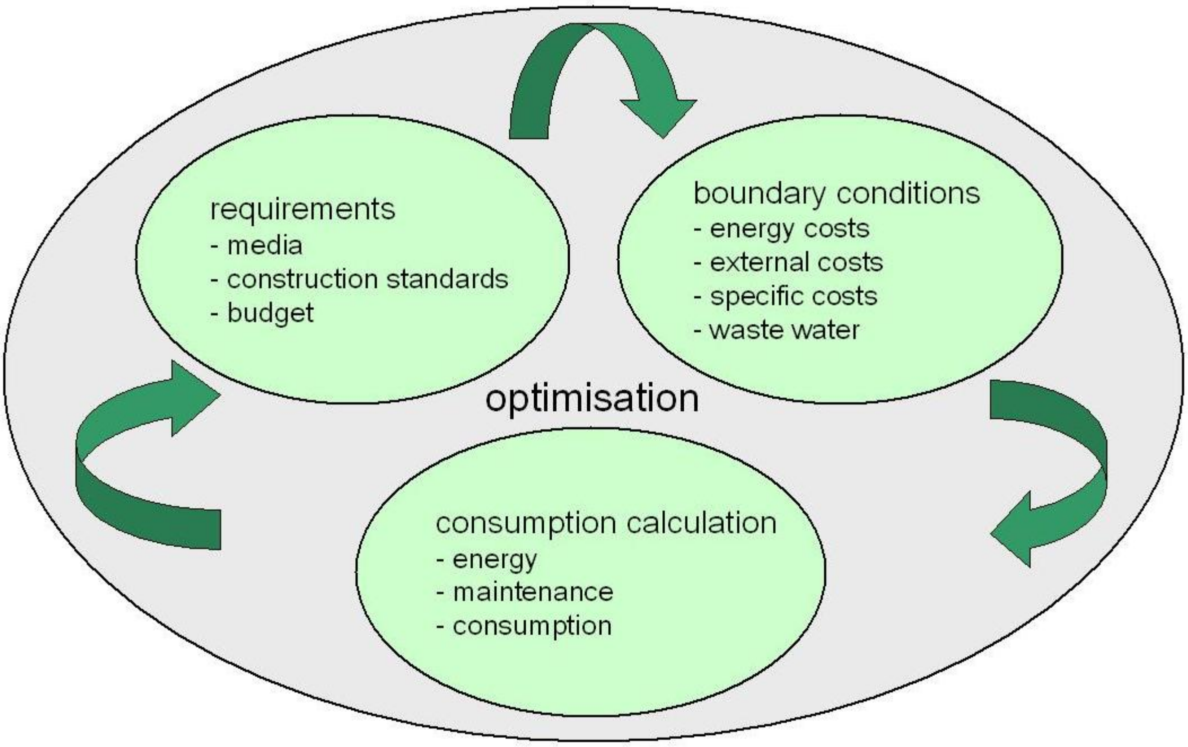

Figure 4. *Facility management process flow chart*

2.4 Urban design

The main aim of the group urban design was the analysis of urban aspects of existing or new industrial estates. Such aspects are important for the owner and investor searching for an optimal area and also for the city officials for planning and allocating of industrial areas. Figure 5 shows the principles of planning.

The evaluation of urban design was distinguished in three categories:

- function and economic qualities
- design and social qualities
- ecological qualities and environmental technology

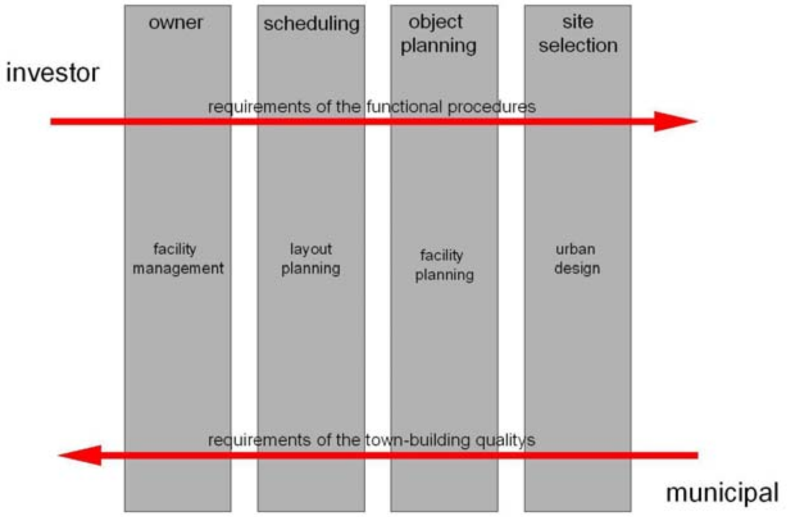

Figure 5. *Concept of urban design criteria*

In a first category the measurable indicators e.g. distances, areas, time and consumptions are explained and rated. In a second category aspects like the identity of the employees with their work station and the integration of the industrial facility into the surroundings was regarded. A rating of this category can only be performed by using qualitative terms (good or bad).

Benchmarking of the category ecological qualities and environmental technology is carried out with questions whether certain methods or technologies are used. The rating process starts with the parcel and its near surroundings (field of interest of the investor) followed by taking into account the industrial area and quarter and ending with the aspects of the city and region.

3 LCE-Tool

3.1 Basics

The main ambition of the research project was the development of a software tool (LCE-Tool) which allows the user to perform an integrated analysis of a planned industrial facility, taking into account ecological, economical and social aspects during the whole service life. The LCE-Tool enables the user to perform a lifecycle analysis including a comparison between different design options of his planned industrial facility. The results are shown comprehensibly in graphics and charts. The LCE-Tool was not developed to carry out preliminary calculations with exact actual costs, but to provide the user useful information by comparing different layouts.

In order to allocate the demands for the facility the user has to answer several questions at the beginning. Most questions are provided with default values to simplify the utilisation. The given values are based on knowledge and long time experience. All values can be corrected or updated by the user individually. In addition most questions and answers are provided with help functions.

The asked questions are divided in four groups. In addition the social indicators are requested (see chapter 3.2). The main topics are:

- operating demands (number of employees, utilisation of the building, demands of area, building and enclosed space)
- building specifications (foundation, supporting structure, exterior walls, wall cladding, interior walls)
- technical equipment (media, heating, ventilation, air conditioning technology, renewable energy, illumination)
- social indicators
- industrial area

Main component of the calculations are the lifecycle costs of the building. The calculation is based on the German DIN 276 [4]: group 300 for the main construction, group 400 for the technical equipment. Furthermore the costs for the group 100 (parcel), 600 (equipment), 200 (preparation) and 500 (outdoor facilities) can be complemented individually.

A characteristic attribute of industrial constructions is the quite short useful life compared to residential buildings. Particularly in the automotive industry the demands of a facility may change all 4 - 6 years with a change of the product line-up. In the LCE-Tool the user can select between a short-term usage (5 years), mid-term usage (15 years) and a long-term usage (30 years). Usually short-term usage of facilities leads to low-cost buildings and ecological aspects are not really taken into account. Instead of minimisation of the building costs the LCE-Tool gives the user an optimisation proposal of the economic and ecologic lifecycle costs.

The planned service life duration also influences the demands for annual maintenance. For the first five years no maintenance costs are included so that short production intervals are taken into account. After five years the costs for the maintenance are calculated by a percentage linear approach based on the total invest costs, starting with 0.15 % in the sixth year and ending with 0.60 % in the twentieth year. The costs for reconditioning of the technical equipment are only calculated for service life spans longer than twenty years. In this case an annual percentage saving for repairing is calculated based on the invest costs for the equipment.

After finishing the input of all known data and adopting the unknown default values the user gets the possibility to compare different projects to obtain an optimal solution for his demands. All generated data are also shown in graphics. There are four different graphics forms:

- radar diagram (relative percental comparison)
- bar diagram (absolute comparison)
- overview (numerical values of the calculation)
- chronological development (comparison of ecological aspects)

3.2 Social indicators

Although economy is the determining factor for decisions, the benchmarking of social aspects, so called soft factors, is implemented in the LCE-Tool, too. For this purpose several factors to evaluate and to develop the concept were implemented. A main target is to benchmark the social aspects from the perspective of a worker of the facility. For this purpose indicators like the room climate can be worked out. A problem is to describe and to balance the three pillars of sustainability equally. The “hard” facts economy and ecology can be assessed quantitatively. The benchmarking of the “soft” facts is carried out by an estimation of positive and negative aspects or situations.

To evaluate the “soft” aspects the user has to answer a number of questions. The questions concerning the social indicators distinguish between three aspects:

- building culture / building aesthetics
- physical surroundings at the workstation
- communication / design

Building culture and aesthetics takes into account if the industrial facility is planned with architects, designers and special consultants. The influence of these specialists for the architectural competition guarantees a maximum of individuality of the concept and a high identification of the employees with their industrial facility. The comprehension of several specialists for details allows the user of the LCE-Tool a detailed planning with innovative ideas and utilisation.

Physical surroundings describes the individual acclimatization, the intervisibility to the outside, glare shield and the prescribed intensity of illumination at the workstation. The individual acclimatization is divided into central and peripheral regulation. The evaluation is combined with the factor glare shield, because the generation of heat at the workstation is not only influenced through the regulated temperature but also through the incident sunlight. The additional installation of a humidifying machine at the workstation redounds to an increased well-being, because the comfortableness is influenced by the humidity and the temperature. To receive optimal conditions at each workstation the lighting conditions have to be observed. To influence the lightning conditions, three factors have to be kept in mind. First off all a workstation with intervisibility to the outside influences the well-being positive and keeps the employees in their natural circadian rhythm. But intervisibility also means that in disadvantageous cases the incoming sunrays are disturbing certain work processes e. g. at computer workstations or paint shops. To avoid unwanted diffuse sunrays a glare shield on the outside of the facade is necessary. If the working station is illuminated with artificial light the valid regulations and guide lines have to be regarded.

Communication and design deals with the opportunities of the layout structure. The main criterion is not the architectural design but the functionality, like the accessibility for handicapped people, design of logistic (goods and people) and so on. The evaluation of all answers for the social indicators is shown graphically and numerically to the user. Figure 6 shows an example of an evaluation of a facility. Green stands for very good, orange for an average and red for an amiss social compatibility. The numerical summarization is shown to the user numbers from one to ten. Seven to ten is very good. Three to six means that the result is average. Some issues of the social compatibility could be upgraded. One to three points mean, that the planned industrial facility only fulfills the minimum requirements.

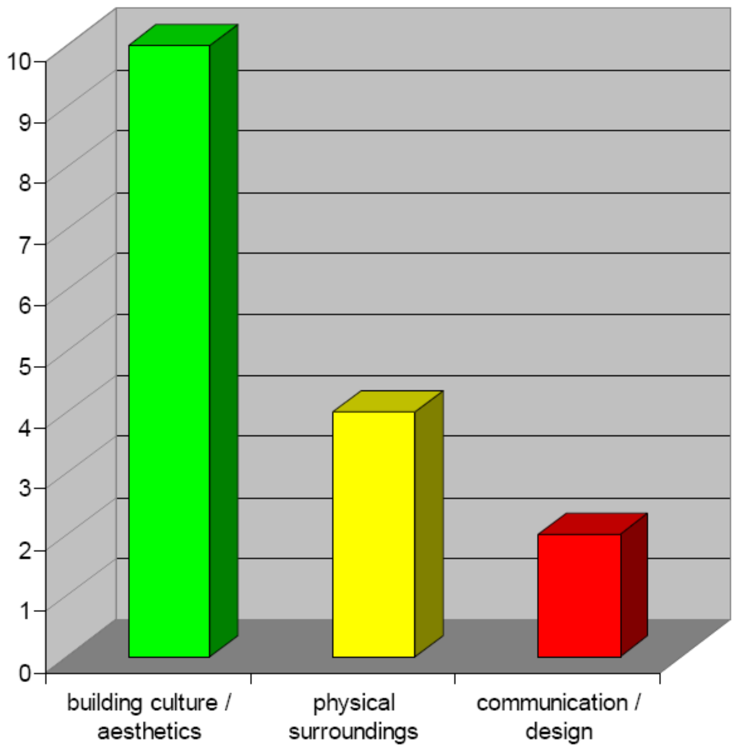

Figure 6. *Results of the analysis of the social indicators*

4 Transfer to practice

The aim of the project WIN-LCE was the development of a software tool which is easy to handle in practice. Before the appliance into practice all project partners did several internal tests to eliminate malfunctions and software problems. Simultaneous all of the project partners worked out a rating sheet for potential users to describe their problems and malfunctions during handling the LCE-Tool.

Another validation before applying the LCE-Tool into practice was the internal testing in the working group facility planning. All demands and facts of the reference objects (see chapter 2.2) were entered in the LCE-Tool to proof, if the decision to built the facility in its way was ecologic, economic and social sustainable.

After the internal validation of all working groups and the release of a new version the LCE-Tool was handed out to some companies which were planning new facilities or even finished new buildings for their companies (major automotive constructor and medium sized manufacturers) to perform their own tests. Several discussions and the filled out rating sheet gave the WIN-LCE group useful information about the requirements of the practice.

5 Conclusions

With the LCE-Tool the user gets a software tool which is easy to handle. It allows him to compare some different facility layouts already in an early stage of planning. But the LCE-Tool is not suitable for preliminary calculations, for this purpose other programs are available. The graphical overview gives the user the possibility to influence the layout and planning of his facility very early. In this release the LCE-Tool is very useful for investors and planners. Indeed the informational value, the correctness and the options could be multiplied in the future with a widening of the data base.

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Monitoring protocol of carbon dioxide in the historic center of Naples (Italy)

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Abstract

The research is part of debate concerning climate change [1-5] in relation to the effects of construction system; the study complies to the measures proposed in act 2002/358/CE of the European Commission, regarding the approval of the Kyoto Protocol. [6]
The research aims at applying the content of the European Commission act on the fight against climate change [7] , within the historic center of Naples. It investigates the potential reduction of carbon dioxide emissions within urban texture.
A sampling campaign is done to measure thermal, luminous and chemical environmental parameters, which condition the amount of CO^2 produced. This campaign is conducted with respect to a monitoring protocol, which requires data collecting in semi-confined spaces, made up of court yards.
The cases investigated illustrate the effects of the dynamics and methods of production and movement of CO^2 within urban settings, in relation to chemical/physical components and types of construction.

Keywords: rehabilitation, monitoring, carbon dioxide, reduction, emissions

1. Aims

The main aim of the search is surveying of the behavior and the performances of the buildings and the open spaces, for the rehabilitation of the architectural heritage of the historic center of Naples.
The search investigates the potential reduction of carbon dioxide emissions within urban texture, thereby binding the constructive analysis of the courtyards to the measurements of carbon dioxide.
The courtyards of the historic center are passages between the buildings and the streets; the courtyard represents traditional construction in Naples, as a filter between internal and external space.
The courtyards [11] were designed for work activities, and as places of congregation, as well as places where activities and tradition prevail; however over the years the use of the courtyard transformed itself from a gathering and workspace to the current car park adaptation.
The objectives for the rehabilitation [8-9]of the courtyard are constituted by the restoration of current usability requirements, as well as restoration of the traditional activities, lost throughout the years.

2. Methodology

In order to estimate the actual presence of carbon dioxide in quantitative terms, a sampling campaign is done to measure thermal, luminous and chemical environmental parameters, through the use of multibuyer BABUC/A, a mobile station for the environmental monitoring.
The campaign has been realized in accordance to the measurement of carbon dioxide protocol, designed for semi confined spaces; it aims at accurate and exhaustive data parametershas been accomplished in accordance with the protocol that can be divided into the following phases :
selection of the site subject to environmental monitoring, and identification of the perimeter of the area, exposure, the various sources of co2;
identification of interior points in which to carry out the measurements;
indication of the frequency of measure, established in quarterly intervals;
definition the length of measurement (24 hours), with collection of data at 15 minutes intervals;
setting of the parameters of the multibuyer and start of the measures;
collection of the data;
elaboration and evaluation of data;
completion of the Cards of measurement of carbon dioxide in the courts of the historic center of Naples.

3. Material instruments and resources

The material resources available for the realization of the monitoring campaign are constituted by the following equipment:

- instrument for the environmental monitoring;
- thermometric probe for generic measuring;
- ventilated probe;
- anemometry probe;
- luxmetrica probe for exterior ;
- infrared probe for the measuring of the CO_2 concentration (field 0..3%).

3.1 A work station for environmental monitoring - Multiacquisitore BABUC/A

Multibuyer BABUC/A consists of instruments, sensors, and programs software for the acquisition, and the elaboration of a great variety of sizes. The instrument has universal connections, through which any combination of sensors of various type is possible, having the ability to configure them automatically.
Work station BABUC/A is composed of:

- numerical keyboard with 21 keys and display LCD 20 characters x 4 lines, with 9 feeding is to Volt with inner batteries or 220 local p0wer source Vca;

- thermometric probe for generic measuring (Fig. 1);
- relative humidity probe (Fig. 2);
- anemometry probe (Fig. 3);
- luxmetrica probe for exterior (Fig. 4);
- probe for the measurement of carbon dioxide concentration (Fig. 5);

The survey has a duration of 24 hours and previews an acquisition to intervals of 15 minuteren, of the following parameters:

- temperature;
- relative humidity;
- relative humidity;
- velocity of the air;
- intensity of turbulence of the air;
- illumination;
- air quality (CO2).

3.2 Used probes

Wet-bulb temperature probe

The probe is designed in compliance with norm ISO 7726. The wet-bulb temperature with natural ventilation corresponds to the temperature of a sensor covered with a wet sheat, subject to natural ventilation and protected from radiation.

Relative humidity probe

The probe is designed in compliance with norm ISO 7726 " Thermal environments - Specifications relating to appliances and methods for measuring physical characteristics of the environment. This probe allows for measuring of relative humidity and related parameters (due temperature, air enthalpy, absolute humidity). Relative humidity probe is constituted by two temperature sensors; the first one measures the dry bulb temperature of the air, the second one, covered by a hydrophilic sheath, measures the wet-bulb temperature with forced ventilation. In the pipe where the two sensors are lodged, protect from solar radiation or of other nature, the air is forced by a fan at a speed of approximately 4 m/s.

Anemometric probe

Anemometric probe measures the intensity of turbulence in accordance with norm ISO7726. Because of its quick data collection (a reading every 100 mps), the probe measures the speed of the air, calculates the average and standard deviation every 4 seconds.

Figure 1: Thermometric probe for generic measuring

Figure 2: Relative humidity probe

Figura 3: Anemometry probe

Figura 4: Luxmetry probe dioxide

Figura 5: Probe for the measurement of carbon concentration

<u>Luxmetric probe for external</u>

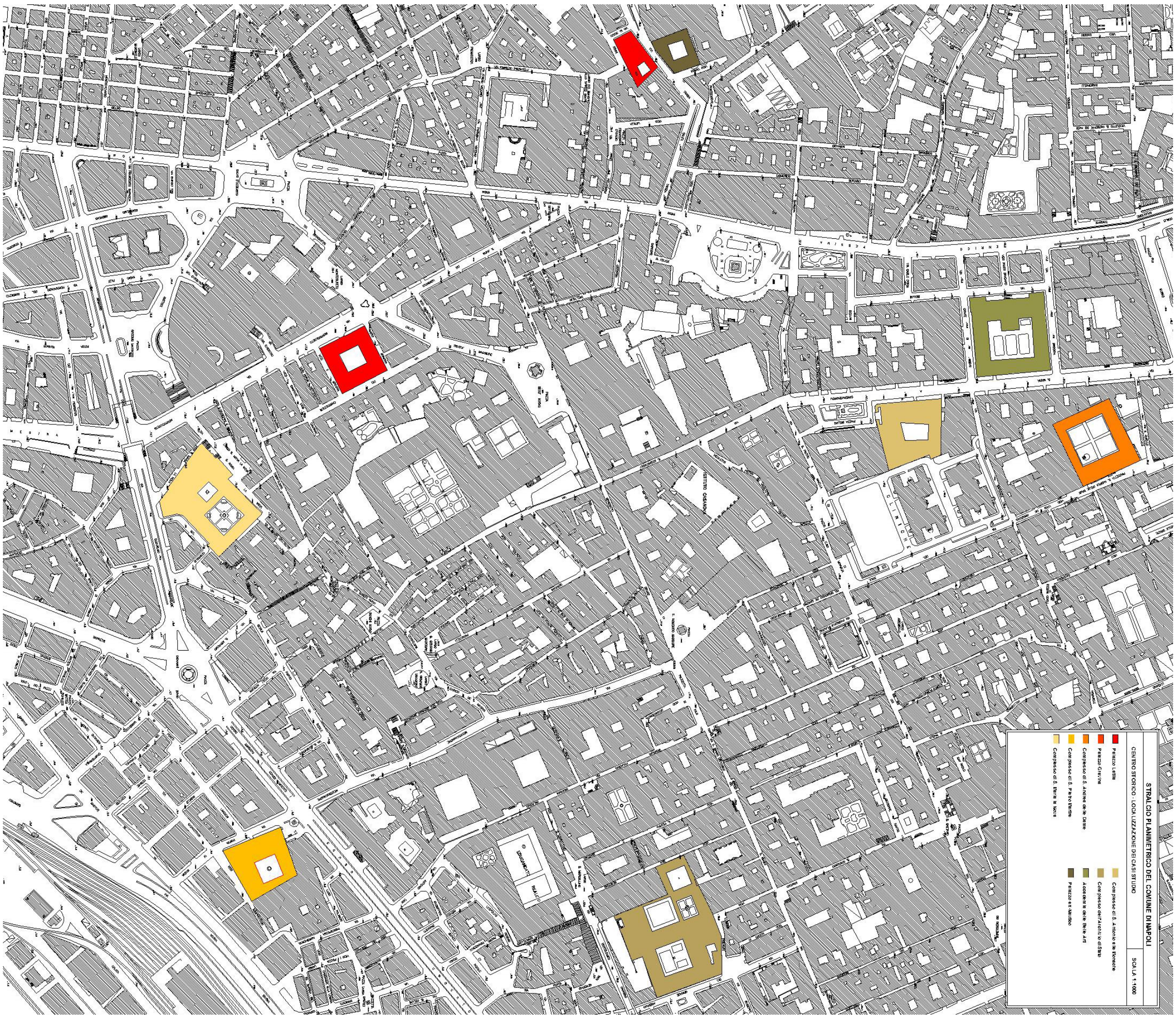
Luxmetric probe for external measures according to the response of human eye, thereby verifying and monitoring the levels of illumination and the dishomogeneity spaces of this parameter indicated in norms ISO 8995 and UNI10380.

<u>Infrared probe for measuring of the co2 concentration (field 0..3%)</u>

The CO2 concentration allows for the estimation of the quality of the chancing of the air, in relation to the characteristics of the introduced air and to the production of polluting agents. Moreover, it allows as to verify if the performances of the ventilation system/air conditioning are suitable to the effective use of the premises (e.g. presence of persons and smokers at various times of the day, presence of polluting devices, etc).

4. Case studies

The case studies are based on the courtyards of the buildings of the historical center; the courtyards of the historic center are passages between the buildings and the streets; the courtyard represents traditional construction in Naples, as a filter between internal and external space.
Nine case studies have been completed since the surveying began in July 2008; the buildings surveyed are identified in the following map:



4.1 "Measurement of carbon dioxide in the courts of the historic center of Naples"

The process of organization of data collection is supported by a card, for menaging of multiple data. The card is a vehicle to understand urban fabric by integrating environmental parameters with construction features of the building.
Specifically the card is divided into three macro areas:

- the building [11-12-13];
- the courtyard;

- the environmental measurements [10].

5. Conclusion

In this initial research phase, the protocol for the measurement of co2 has been designed. Subsequently, the protocol was experimented through the nine case studies. The calibration of the protocol was carried out upon the misfunction of the application of the protocol itself.
The synoptic table of the initial stage, listed case by case, follows:

Case study n. 1 "*Palazzo Latilla*"

Period of survey	Surface total building (m^2)	Uncovered surface (m^2)
14-15 july 2008	724	125

Monitoring of carbon dioxide, at 6 hours intervals (ppm)				
1 p.m.	**7 p.m.**	**1a.m.**	**7a.m.**	**1 p.m.**
1014	933	933	889	1001

Case study n. 2 "*Palazzo Gravina*"

Period of survey	Surface total building (m^2)	Uncovered surface (m^2)
24-25 july 2008	2968	457

Monitoring of carbon dioxide, at 6 hours intervals (ppm)				
1 p.m.	**7 p.m.**	**1a.m.**	**7a.m.**	**1 p.m.**
578	696	535	678	622

Case study n. 3 ***Housing Complex "S. Andrea delle Dame"***

Period of survey	Surface total building (m^2)	Uncovered surface (m^2)
25-26 september 2008	5062	1966

Monitoring of carbon dioxide, at 6 hours intervals (ppm)				
1 p.m.	**7 p.m.**	**1a.m.**	**7a.m.**	**1 p.m.**
908	871	821	889	902

Case study n. 4 ***Housing Complex "S. Pietro Martire"***

Period of survey	Surface total building (m^2)	Uncovered surface (m^2)
8-9 october 2008	3429.5	1089

Monitoring of carbon dioxide, at 6 hours intervals (ppm)				
1 p.m.	**7 p.m.**	**1a.m.**	**7a.m.**	**1 p.m.**
951	920	926	933	902

Case study n. 5 ***Housing Complex "S. Maria la Nova"***

Period of survey	Surface total building (m^2)	Uncovered surface (m^2)
6-7 november 2008	1205	244

Monitoring of carbon dioxide, at 6 hours intervals (ppm)				
1 p.m.	**7 p.m.**	**1a.m.**	**7a.m.**	**1 p.m.**
871	902	895	883	970

Case study n. 6 ***Housing Complex "S. Antonio delle Monache"***

Period of survey	**Surface total building (m^2)**	**Uncovered surface (m^2)**
12-13 november 2008	2611	499

Monitoring of carbon dioxide, at 6 hours intervals (ppm)				
1 p.m.	**7 p.m.**	**1a.m.**	**7a.m.**	**1 p.m.**
864	964	846	877	875

Case study n. 7 ***Housing Complex "SS. Severino e Sossio"***

Period of survey	**Surface total building (m^2)**	**Uncovered surface (m^2)**
27-28 november 2008	7294	985

Monitoring of carbon dioxide, at 6 hours intervals (ppm)				
1 p.m.	**7 p.m.**	**1a.m.**	**7a.m.**	**1 p.m.**
1026	902	895	908	821

Case study n. 8 **"*Accademia delle Belle Arti*"**

Period of survey	**Surface total building (m^2)**	**Uncovered surface (m^2)**
19-20 dicember 2088	4724	1754

Monitoring of carbon dioxide, at 6 hours intervals (ppm)				
1 p.m.	**7 p.m.**	**1a.m.**	**7a.m.**	**1 p.m.**
945	920	871	908	858

Case study n. 9 "Palazzo *Ex- Nautico*"

Period of survey	Surface total building (m^2)	Uncovered surface (m^2)
22-23 dicember 2008	1167	289

Monitoring of carbon dioxide, at 6 hours intervals (ppm)				
1 p.m.	**7 p.m.**	**1a.m.**	**7a.m.**	**1 p.m.**
889	858	902	908	933

Analyzing the obtained readings and concluding that they will have be increased by 2012, as indicated in act 2002/358/CE, of the European Commission, the following question arises:

- Could be the restoration of the conditions of usability and the performance of courtyards as work and/or congregation space be the ***future scenario*** to reduce co2 emission?

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Economical analysises to sustainability

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Abstract

The paper includes a review of sentence of sustainability indicators, an internationally harmonized model for life cycle economics and an analysis example concerning energy saving renovation of an old block of flats. The following list shows examples of issues that can be taken into account in life cycle economics with essential benefits:

- energy efficiency → lower maintenance cost, "green building"
- life cycle quality → lower renovation cost, better user-satisfaction
- flexibility → lower modification cost, better user-satisfaction
- easy change of building parts → lower renovation cost and higher rate of recyclability

Life-cycle economical, energy efficient, eco efficient, healthy and social facilities are quite similar: durable enough and desirable with functional, change-flexible and unrestricted spaces as well as reliable, advantageous and undamaged systems and other products and materials.

Economical analysis's are to be utilized by different kind of organisations in building and facility trades when comparing concurrent technical solutions with each other and making cost-effectiveness, profit and cash flow analysis's. The life-cycle economical comparisons should be focused on those characteristics and products with real importance. Advising shall be organized through many kind of channels and training programmes.

Keywords: life cycle assessment, environmental declaration, life cycle cost, sustainability indicator, building product

Sustainability indicators for building

The implementation of the principles of sustainable development is a fundamental goal of EU policies. ISO TS 21929 defines a framework for sustainability indicators of buildings. According to it the following economic flows are related to the life cycle economics of a building:

- investment: site, design, product manufacturing, construction,
- use: energy consumption, water consumption, waste management etc.,
- maintenance and repair,
- deconstruction and waste treatment,
- development of the economic value of a building, and
- revenue generated by the building and its services.

The economic indicators indicate monetary flows connected to the building life cycle.
When comparing different design options, performance aspects are the underlying factor. Building performance is gaining stronger consideration in the connection of sustainable building,

and thus also the management of building performance can be seen as an important part of sustainable building process.

Life cycle economics

Life cycle costing (LCC) is a technique for estimating the cost of whole buildings, systems and/or building components and materials, and for monitoring the occurred throughout the lifecycle. The technique can assist decision-making in building investment projects. LCC is used to evaluate the cost performance of a building throughout its lifecycle, including acquisition, development, operation, management, repair, disposal and decommissioning. The analysis model presented is in direct connection to European promotion campaign of LCC co'ordinated by Davis Langdon Consulting (UK) and is based on internationally harmonized models [3,4,7].

The main content covers principles of life-cycle economics with reference to

- design options/alternatives
- investment options
- decision variables and
- uncertainty and risk.

The following list shows examples of issues that can be taken into account in life cycle economics and with essential benefits:

- energy performance → lower maintenance cost
- life cycle quality → lower renovation cost, better user-satisfaction
- flexibility → lower modification cost, better user-satisfaction
- easy change of building parts → lower renovation cost and higher rate of recyclability

Because of the predictive nature of life cycle costing methods, sensitivity analyses are often important in the connection of life cycle economics. Sensitivity analysis may be based on classification including for example the three steps: optimistic – probable – pessimistic.

Economical analysis's may also be drawn up in early stages of building design if there is information available on reference data of building related life cycle costs. Figure 1 outlines the possibilities to utilise life-cycle based decision making for example when comparing alternative technical solutions or when analysing cost-effectiveness, profit and cash flows.

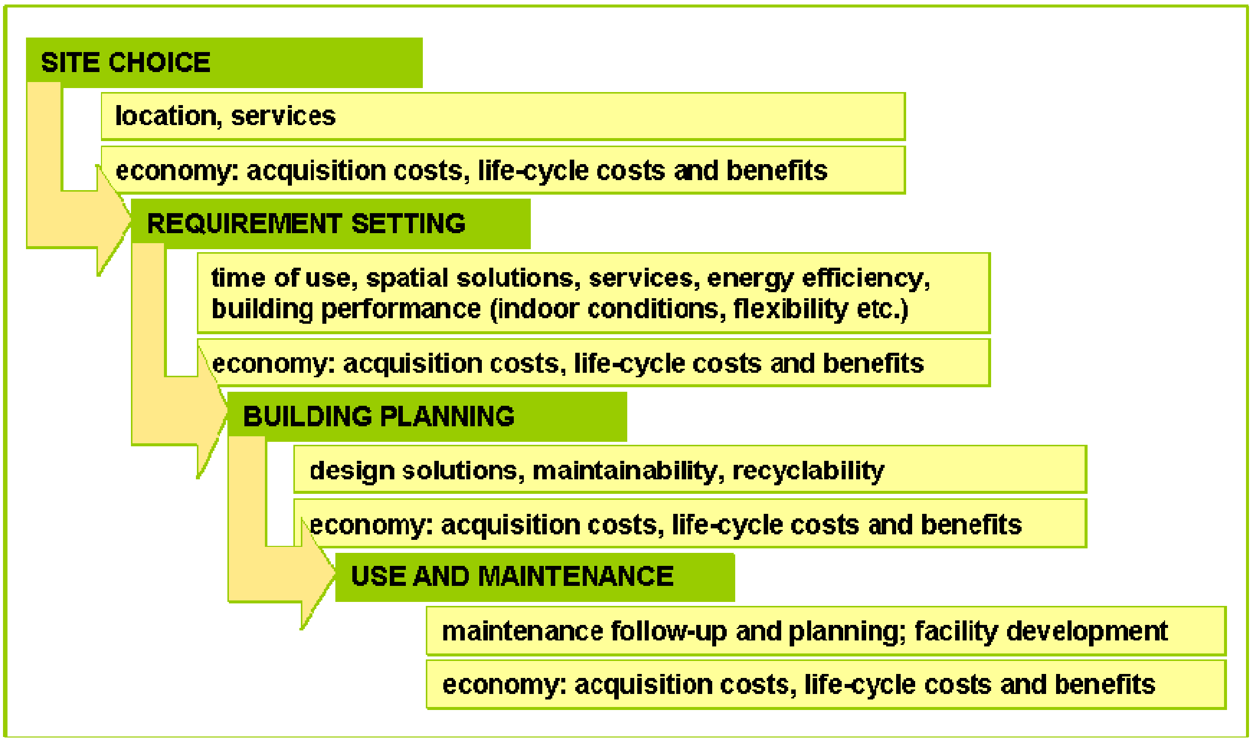


Figure 1. Main phases and objects of life-cycle based decision making.

In facility investment and space acquisition the main interest is concentrated on location, use of spaces, time of use, energy economy and adaptability. Calculations may also be utilised in comparing life-cycle tenders. Based on the experiences of a big Finnish facility owner, Senate Properties, within life-cycle based decision making, it is important to be able to direct the focus in each stage of the process. Within building processes the life-cycle based product selection should focus on facades and windows, base floors and roofs, separation walls, coatings, furniture, HVAC and electrical systems and routings as well as information systems. By use and maintenance the important life-cycle areas are planning, use directions of ventilation and information technology as well as applying efficient maintenance methods. Facility development should be based on building condition determination, suitable new construction practises, definition of wanted performance and definition of eligibility with user's processes. The solutions are mainly based on the original state of the building: appearance, spaces, level of energy consumption, rate of flexibility and technical systems. The life-cycle benefits may be compared with a corresponding new building.

We can define different periods of life cycle: Functional life cycle may be very short (1…3 years), economical life cycle being based on rent or funding time is longer (10…30 years), technical life-cycle is a period between construction and disposal (for example 50 - 100 years). The choice of life-cycle period should be based on real needs of decision making. It has a remarkable influence on cost distribution. Classification of life cycle costs is very alike in different standards and solutions (Table 1), the important thing is that those cover all costs within the chosen period, those are estimated in a realistic way and the time correction has been made right.

The economy of energy saving concepts and HVAC systems is becoming more and more interesting. Then the special economical criteria's concern

- savings in consumptions and reductions of emissions
- effects on inner climate
- changes in investment costs
- changes in life cycle costs within chosen period

- effects on (resale) value and (rental) profits
- pay back time

It has as follows been analysed economics of energy effective renovation.

Analysis example: The economy of energy effective renovation

The economy of energy renovations (analysis example in table 2) may be developed as follows:

- combining it into certain renovation concepts (table 1)
- utilizing possible potential of building effectiveness
- utilizing possible investment supports

Table 1. Examples on renovation concepts.

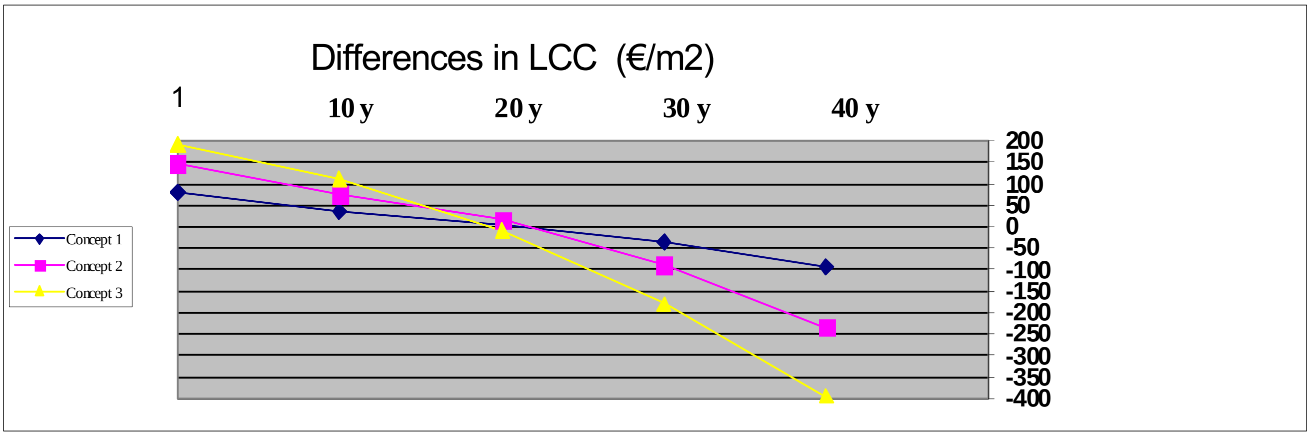
Action	**Renovation concept 1**	**Renovation concept 2**	**Renovation concept 3**
	Renewing of windows and ventilation system, setting an effective heat recovery system and improving tightness.	Improving tightness and insulation of building envelope, renewing windows and HVAC systems.	Remarkable improving of tightness and insulation of building envelope, life cycle optimized renewing of windows and HVAC systems.
Improving tightness and insulation of envelope	-5 %	-15 %	-25 %
Renewing of windows and doors	-10 %	-10 %	-15 %
Renewing of HVAC systems	-10 %	-25 %	-35 %
Altogether	**-25 %**	**-50 %**	**-75 %**

As noticed in table 2 the economy of remarkably energy saving renovations take time (even 20 years) but do rise the resale values. However the differences in economy between concepts are small. The rise of building cost (about 200 €/m^2) may be quite critical. The energy saving potential of old buildings is usually higher than in case of new buildings. The energy efficiency improves even more because of positive changes in inner climate. However everything is not economical - for example outer insulation of facades. We should have more developed integrated (facades, windows, HVAC) solutions for easy and cheap ways of energy saving renovations.

Life Cycle economy of covering improving of energy efficiency requires also real rise of energy prices as well as investment and loan rent supports. In case of lower consumptions the importance of green ways of energy production become large too. Also the role of user will be more and more significant..

Table 2. Case example: Economy of energy saving renovation concepts.

Renovation of an old block of flats			**Renovation concept 1**	**Renovation concept 2**	**Renovation concept 3**
Cost level:	1/2009				
Heating way :	district heating				
Calculation cycle :	40 y (→ year 2050)				
Starting price of heating energy :	0,05 €/kWh				
Starting price of electricity energy:	0,10 €/kWh				
Real rise of energy price:	3%/y				
ECOEFFICIENCY		**Basis**			
Heating	$kWh/m^2/y$	200	150	100	50
Electricity	$kWh/m^2/y$	10	12	9	6
Inner climate class		S3	S2	S2	S2
Energy class		F	D	B	A
CO_2	$tn/m^2/40$ y	2,2	1,7	1,2	0,7
LIFE CYCLE ECONOMY (present value)			Cost diff €/m^2	Cost diff €/m^2	Cost diff €/m^2
Diffences in building cost		**B**	**+80**	**+145**	**+190**
Improving insulation of envelope			0	+40	+70
Renewing of windows and doors			+30	+45	+60
Improving tightness			+15	+40	+50
Development of ventilation parts			+35	+35	+40
Integration of heating parts				-15	-30
Differences in maintenance cost		**M**	**+10**	**+25**	**+20**
Difference in heating cost		**H**	**-195**	**-390**	**-585**
Difference in electricity cost		**E**	**+10**	**-15**	**-20**
Difference in Life Cycle Cost		**B+M+H+E**	**-95**	**-235**	**-395**
Price of loan money			**+30**	**+65**	**+85**
Investment support			**-50**	**-50**	**-50**
Difference in Life Cycle Cost (indirect)			**-115**	**-220**	**-360**
Pay back time years			**21**	**20**	**18**
Difference in Resale value			**+3…+5**	**+5….+10**	**+10…+15**



Conclusions

There are different needs for life-cycle based decision-making on different levels of activities to be utilized in different kind of organisations. As the starting point of generalizing life-cycle based decision making is to specify concepts and calculation model as far as focusing the most essential life-cycle characteristics on different levels of facility business. They also cover the most important objects of technology development. Generalizing of life cycle contracts shall happen at the same time both in producing companies and in client organisations.

Generalizing of life-cycle optimized facility concepts should mean

- Reduction of heating and electricity energy making it easier to optimize energy management and increase importance of renewable energy resources.
- Increase of both GNP and employment and transferring labour inputs from energy producing countries to home lab and from wasting to recycling services.
- New kind of business possibilities (for example building concepts, coating structures, recycling products).

Life-cycle economical, energy economical, eco efficient, healthy and social facilities have quite similar criterias: functional, change-flexible and unrestricted spaces as well as reliable, advantageous, durable, energy saving, undamaged recyclable systems, other products and materials. There shall be combined the most economic and eco efficient performance characteristics to the life-cycle optimized technical solutions in the best practise (or next practise) building concepts.

The public sector has a central role in promoting life cycle advantageous solutions through its own production and giving directions and building codes. This requires commonly approved technology foresight systematics. The private sectors are applying directions and codes in life-cycle optimized ways and seeking new areas of business which aim at high profits through intensive innovation processes. This means growing international value networking.

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Assessment of the moisture and thermal performance of repaired building facades

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Abstract

Cracking of concrete, corrosion of reinforcement, spalling of the concrete cover, and surface scaling are the four most common and important types of deterioration of reinforced concrete. Deterioration of concrete can be a result from environmental factors including moisture, temperature, the presence of chlorides, and carbon dioxide. In addition, moisture will increase the heat flow through a structure and thus increase the consumption of heating energy. The continuous monitoring of temperature and relative humidity provides a good piece of information about the long-term performance and deterioration of building facades.

The objective of the research is to improve the use of the ICT (Information and Communication Technology) in the real estate and construction sector. This study consisted of laboratory work and field measurements. The laboratory work focused on designing and testing a monitoring network system. The field measurements were carried out by monitoring the temperature and relative humidity of three repaired facades. The thermal and moisture conditions were monitored at regular intervals of 15 minutes.

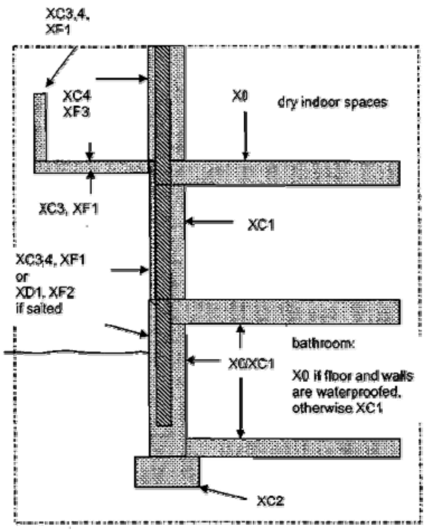
The results of the moisture and thermal monitoring show that the use of ventilation gap allows the moisture to evaporate to the open air from the repaired facade and ensures the dryness of the internal walls. Also the monitoring of facades repaired by adding external wall insulation and a rendering system shows the drying of the old facade after repairing.

Keywords: monitoring, thermal, moisture, repaired facades, assessment

1. Introduction

Deterioration of concrete is one of the basic questions in the life time management of buildings and structures. Two of the most important deterioration factors in buildings subjected to outdoor conditions are moisture and temperature. Moisture is a major factor in physical deterioration processes that are typically caused by restrained moisture movements and freezing, or they can be connected to chemical or biological attacks.

A severe climate may be a reason behind a chemical load on the building. In addition, moisture will increase the heat flow through a structure and thus increase the consumption of heating energy [1]. Exposure classes for the concrete facade structures according to the BY 50, 2004 for different environmental conditions are shown in figure 1 [2].



Class	Corrosion induced by	Sub-classes	Description of the environment
X0	No risk		Very dry
XC	Carbonation	XC1	Dry or continuously wet
		XC2	Moist, rarely dry.
		XC3	Moderately moist
		XC4	Periodical wetting and drying
XF	Freeze-thaw attack	XF1	Moderate saturation with water without thawing agents
		XF2	Moderate saturation with water and di-icing agents
		XF3	High saturation with water without de-icing agents
		XF4	High saturation with water and de-icing agents

Figure 1. Classification of concrete facade structure into carbonation and frost exposure classes BY 50 [2].

The continuous monitoring of temperature and relative humidity provides not only important information for life-time management but also introduces the possibilities of systematic condition monitoring in developing the predictive maintenance of concrete structures.

2. Method

One goal of the research was to develop a thermal and moisture monitoring method to assess the moisture and thermal performance of the repaired building facades. For that purpose, the RHT monitoring network system and RHT monitoring software were developed to gather and analyze large amounts of thermal and moisture data on repaired building facades.

2.1 RHT monitoring network system

The RHT monitoring network system was developed to monitor the thermal and moisture performance of repaired building facades. The RHT network system consists of a controller and nodes where relative humidity and temperature sensors are connected to [3]. The network system may contain up to 200 nodes connected to a twisted-pair CAT5 cable with a maximum total length of 1000 meters. A schematic diagram of the RHT monitoring network system is illustrated in figure 2.

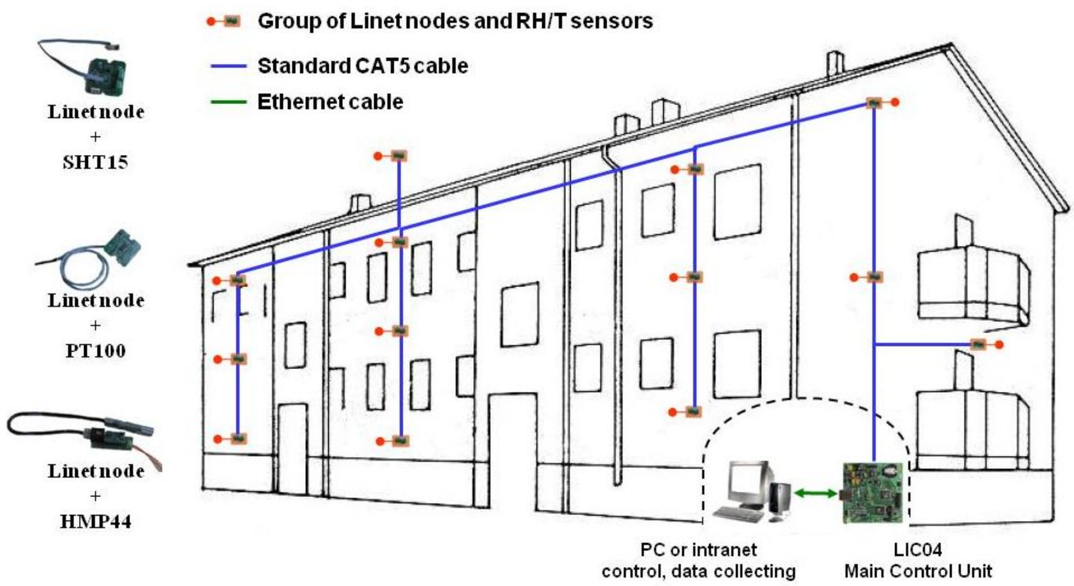


Figure 2. Schematic diagram of the RHT monitoring network system [4]

2.2 RHT monitoring software

The RHT monitoring software communicates between a host computer and the RHT monitoring network system controller, collects relative humidity and temperature data, and processes the monitored data. The software was developed at the laboratory of Structural Engineering and Building Physics using Microsoft Visual Basic 6.0. The RHT monitoring software runs on Microsoft Windows platforms. The RHT monitoring software consists of four basic modules: a system configuration module, a Telnet simulation module, a RHT calculation and output module, and a data processing module [4].

The system configuration module contains two parts: the configuration of the monitored target cross-section and the configuration of the sensors and the nodes of the RHT monitoring network system. The Telnet simulation module is used in communication with the LIC04 controller of the RHT monitoring network system. The RHT calculation and output module is used for calculating the temperature and relative humidity monitoring values, saving the resulting values in ASCII file and displaying the values on the screen. The data processing module processes the temperature and relative humidity monitoring data. The data processing module was developed using Visual Basic for Applications under Microsoft Excel. The graphical user interface of the RHT monitoring software is shown in Figure 3 [4].

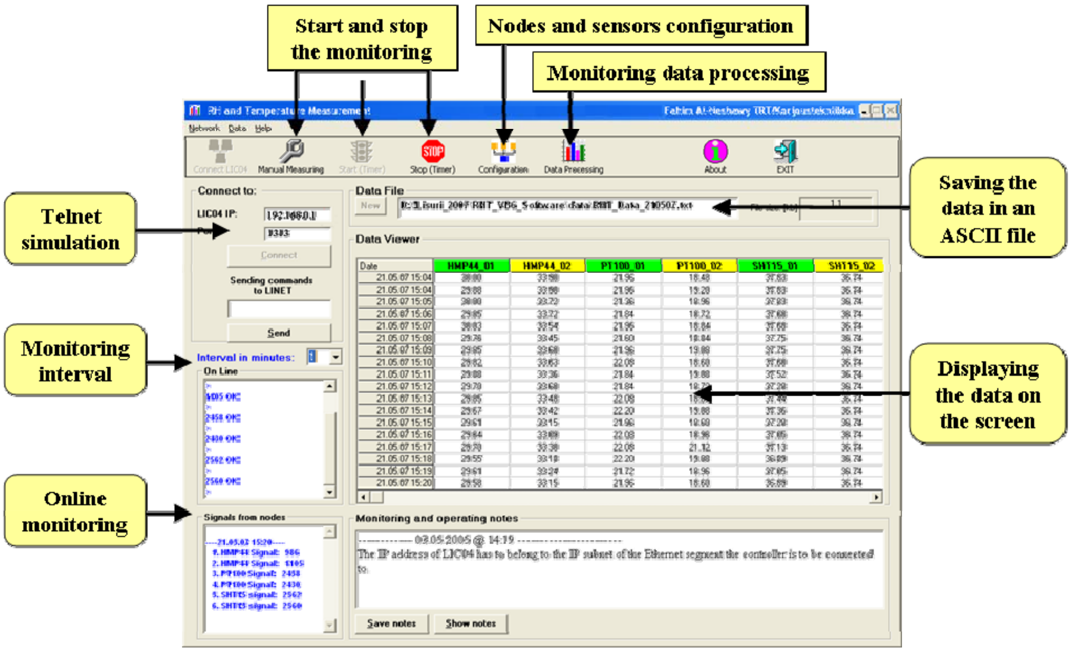
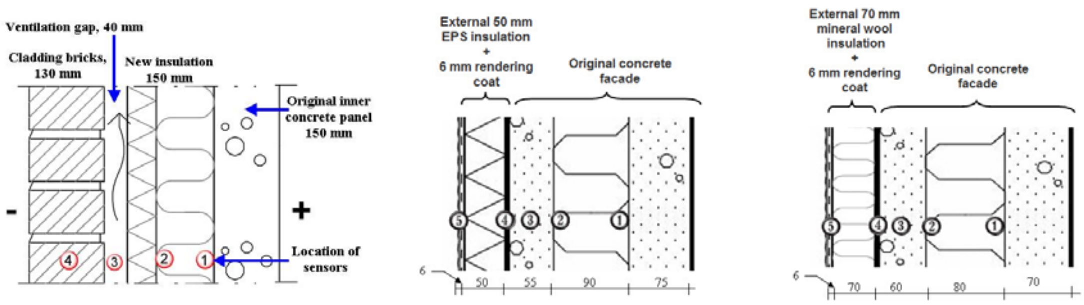


Figure 3. The graphical user interface of the RHT monitoring system [5]

2.3 Monitoring locations and instrumentation

The monitoring of humidity and temperature using RHT-monitoring network system was carried out in three sandwich-type building facades repaired with different methods. The first facade (I) was repaired by adding a new insulation, ventilation gap and cladding with bricks after removing the outer leaf of the original sandwich panel and insulation. The second facade (II) was repaired by adding an external insulation (EPS) and a rendering coat over the original sandwich panel. The third facade (III) was repaired by adding an external mineral wool insulation and a rendering coat over the original sandwich panel.



Facade (I) Facade (II) Facade (III)

Figure 4. Positions of the humidity and temperature sensors installation in the repaired concrete facades (I), (II) and (III).

The relative humidity and temperature sensors installed in all of the repaired facades are shown in table 1. The relative humidity and temperature sensors were installed at points 1, 2, 3, 4 and 5, as shown in figure 4. There were also two relative humidity and temperature sensors for outdoors measurements.

Table 1. Humidity and temperature sensors used on the monitoring system.

Sensor		Monitored parameters and location	Output data
HMP 44	Humidity and temperature sensor made by Vaisala Oy in Finland. (Accuracy of ±2 % to ±3 % RH)	Relative humidity of: • the original outer concrete panel and outdoors	RH (%)
SHT15	Humidity and temperature sensor made by Sensirion in Switzerland. (Accuracy of ±2 % to ±4 % RH and ±0.3°C)	Relative humidity of: • the original insulation • the new external insulation • the rendering system	RH (%)
PT100	Platinum resistance thermometer. (Accuracy of ±0.3 °C at 0 °C)	Temperature of: • the original insulation • the original outer concrete panel • the new external insulation • the rendering system • outdoors	T (°C)

3. Results

3.1 Relative humidity and temperature of the repaired facades

Figure 5 presents the average daily temperature of the ventilation gap air and the outdoor ambient air of the repaired facade (I). The temperature in the ventilation gap was always higher than the temperature outdoors, which increased the air movement from the ventilation gap outdoors.

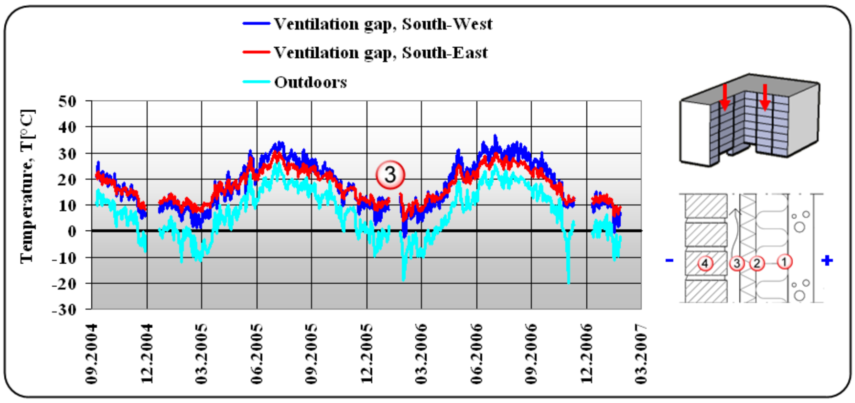


Figure 5. The daily average temperature outdoors and inside the ventilation gap of the repaired facade (I).

The temperature and relative humidity under the external (EPS) insulation and the rendering coat of the repaired facade (II) facing southwest are presented in figure 6. The temperature under the external EPS insulation did not drop below 0°C. The relative humidity under the external insulation varied between 20% and 80% during the monitoring period.

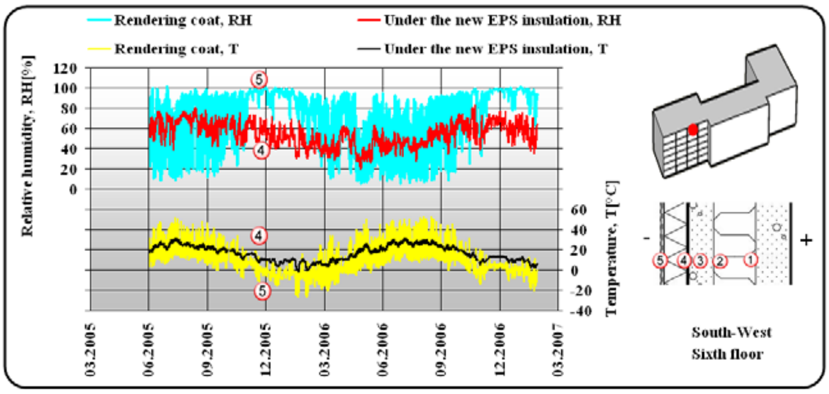


Figure 6. The temperature and relative humidity under the external EPS insulation and under the rendering coat for the repaired facade (II)

The temperature and relative humidity under the external mineral wool insulation and the rendering coat of the repaired facade (III) facing northeast are presented in figure 7. The temperature in the rendering coat varied between -23°C and +35°C. The temperature under the extra mineral wool insulation dropped below 0°C during February 2006, and the minimum measured temperature was -4°C. The relative humidity of the rendering coat varied between 30% and 92%. The relative humidity under the extra insulation varied between 20% and 75% during the monitoring period.

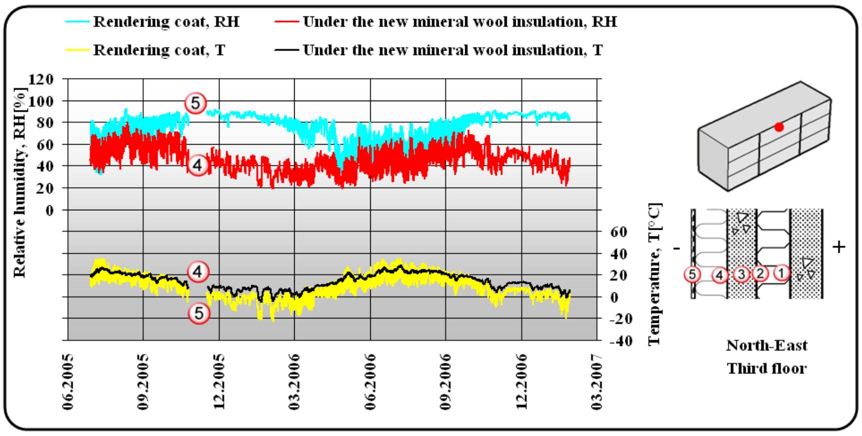


Figure 7. The temperature and relative humidity under the new mineral wool insulation and under the rendering coat for the repaired facade (III)

3.2 Effectiveness of the repairing methods

The saturation deficit of the ventilation gap is the difference between the saturation water vapour content in the ventilation gap air and the actual water vapour content in the outdoor ambient air at the same temperature [6]. The saturation deficit in the ventilation gap of the repaired facade (I) is calculated using equation 1.

$$Ds = v_{sat,gap}(T_{act}, RH_{100\%}) - v_{act,outdoors}(T_{act}, RH_{act}) \quad (1)$$

where:

D_s	is the drying potential between the ventilation gap and outdoors, g/m³
$v_{sat,\ gap}$	is the saturated water vapour content of the ventilation gap, g/m³
$v_{act,\ outdoors}$	is the actual water vapour content outdoors, g/m³
T_{act}	is the actual temperature, °C
RH_{act}	is the actual relative humidity, %

As shown in figure 8, the drying potential between the ventilation gap and outdoors increased during the hottest months of the year. The maximum values of the vapour saturation deficit were 29.6 and 27.8 g/m³ during July 2006 in the southeast and southwest respectively.

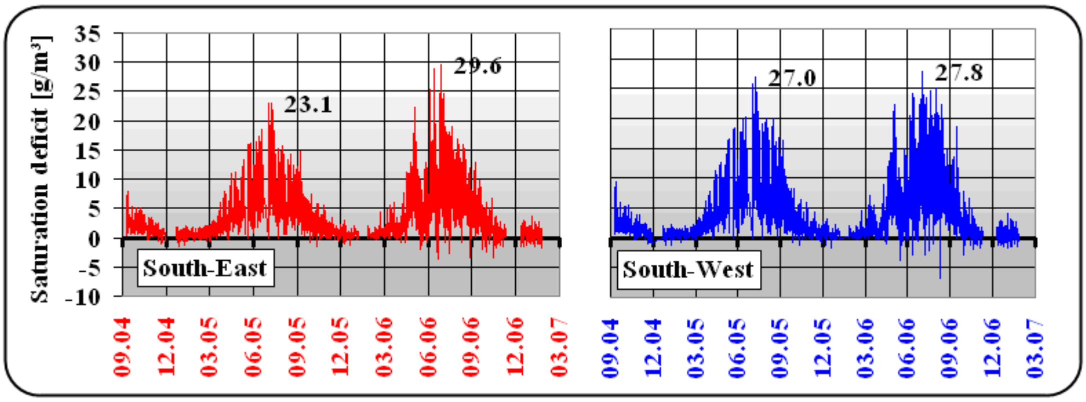


Figure 8. The saturation deficit in the ventilation gap of the repaired facade (I)

Figure 9 shows the drying of the original outer panel of the repaired facade (II) after one and a half years of the installation of the external EPS insulation and the rendering coat. The relative humidity of the outer concrete panel dropped from 97% to 67% in the facade facing the northeast and from 97% to 63% in the facade facing the southwest. The water vapour content of the outer concrete panel dropped from 24 g/m³ (northeast) and 29 g/m³ (southwest) to 20 and 21 g/m³ respectively.

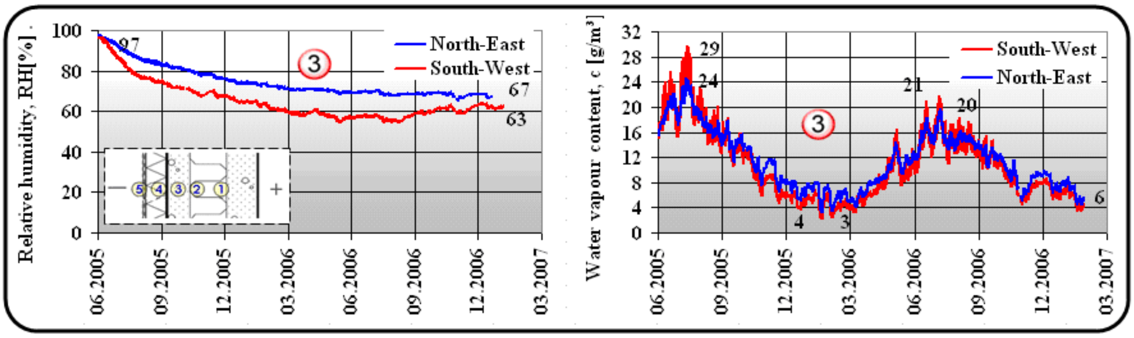


Figure 9. The relative humidity and water vapour content of the original outer concrete panel of the facade repaired by adding an external insulation (EPS) and a rendering coat, facade(II).

Figure 10 shows the drying of the original outer panel of the repaired facade (III) after one and a half years of the installation of the external mineral wool insulation and the rendering coat. The relative humidity of the outer concrete panel dropped from 88% to 67% in the facade facing southwest and from 64% to 54% in the facade facing northeast between June 2005 and February 2007. The water vapour content of the outer concrete panel dropped from 23 g/m³ only on the southwest to 14 g/m³.

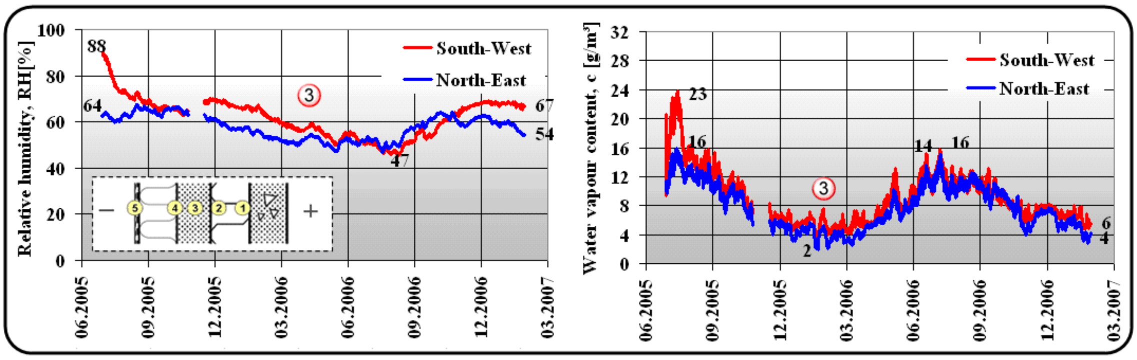


Figure 10. The relative humidity and water vapour content of the original outer concrete panel of the facade repaired by adding an external mineral wool insulation and a rendering coat, facade(III).

As shown in figures 9 and 10, the building facades gradually achieve moisture equilibrium by releasing moisture during the first and second years after repairing.

3.3 Freezing and thawing cycles

The degree of saturation, the freezing rate, the minimum freezing temperature, and the freezing time are the extrinsic factors that affect the frost damage of materials [7] and [8].

Table 2. The freezing rates, the total freezing times and the number of freezing and thawing cycles for the repaired facades (I), (II) and (III) between June 2005 and June 2006.

Repaired facade		Maximum cooling and warming rates (°C/h)		Total freezing times (days)		Number of freezing and thawing cycles	
		cooling	warming	below 0°C	below -6°C	threshold 0°C	threshold -6°C
(I)	Outdoor	-5.8	6.7	57	38	78	50
	Cladding bricks. SW	-4.5	3.4	47	26	47	27
	Cladding bricks. SE	-3.1	4.8	57	34	44	35
	Ventilation gap. SW	-2.1	3.6	29	12	39	24
	Ventilation gap. SE	-1.6	4.0	32	17	49	38
(II)	Outdoor. SW	-6.4	6.9	85	59	62	51
	Rendering coat. SW	-12.2	8.7	85	57	104	70
	Outdoor. NE	-2.4	4.3	75	50	39	32
	Rendering coat. NE	-3.2	6.6	76	50	67	49
(III)	Outdoor. SW	-3.5	4.8	64	27	54	45
	Rendering coat SW	-14.5	13.6	50	35	106	63
	Outdoor. NE	-2.6	4.7	77	50	49	43
	Rendering coat. NE	-3.9	5.1	59	36	62	46

As shown in table 2, the maximum cooling rate of the outdoors at the repaired facade (I) was -5.8 °C/h, and the maximum warming rate was 6.7°C/h. Because of the massive structure of the cladding bricks, the cooling and warming rates in the centre of the cladding bricks and in the ventilation gap air were lower than in the outdoor air. The larger number of cycles experienced in the southwest parts of the repaired facades (II) and (III) is due to solar radiation warming the air and the low thermal mass of the rendering coat.

4. Conclusion

The RHT monitoring network system is very useful for gathering a large amount of data about the thermal and moisture performance of repaired facades, which provides a better understanding of how the environment and the building interact. The thermal and moisture data can be a complement to the visual inspections of the building facades.

By measuring the temperature and relative humidity of building components, we can determine the potential for deterioration, wetting and drying patterns in building components, and changes in moisture content. Monitoring is especially useful when applied to the maintenance and repairing sector.

The number of freezing and thawing cycles experienced by the repaired facades is strongly dependent on solar radiation, which in turn depends on wall orientation and latitude and shading conditions. If the facade is facing southwest, it is exposed to a larger number of freezing thawing cycles and a longer freezing duration than a facade facing northeast.

Documenting the performance of repaired buildings through monitoring can improve the understanding of repairing methods, repairing materials, and structural behaviour of the repaired structures.

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Low Energy Building Concept Symposium -- Japan Report
The Rising Popularity and Prospects of Low Energy Housing in Japan

1. Urban Growth and Natural Environment of Postwar Japan

○ Having achieved widespread urbanization and social development after WWII, Japan is now focused on raising its housing standards to a level comparable to EU.

○ Observations on Japan's natural environment and characteristics of energy consumption

1) Housing market and housing supply now in stable growth phase

	Housing completions	Growth	Total housing stock	No. of households
1973	1,906,112 units	100%	31,058,900 units	31,908,000
1985	1,236,072	65%	39,564,280	38,457,000
2002	1,150,923	60%	53,200,273	48,638,000
2006	1,289,832	68%	54,871,096	51,102,000
2007	1,060,741	56%	–	51,713,000

2) Apartments and prefabricated houses are the mainstream of housing supply

	Apartments		Conventional houses	Prefabricated houses	
	Developers		Conventional builders	Prefab house makers	
1973	596,613 units	31.3%	61.4%	139,146 units	7.3%
1985	527,802	42.7%	42.9%	177,994	14.4%
2002	546,688	47.5%	31.7%	239,391	20.8%
2006	632,017	49.0%	30.4%	265,795	20.6%
2007	469,908	44.3%	32.7%	243,970	23.0%

○ Housing Production Patterns, 1973

2. Distinct Patterns of Apartment and Prefabricated House Supply in Japan

Apartments

Starting in the mid-1950s, public housing corporations including the Japan Housing Corporation and its successors provided a large number of apartments in metropolitan areas. Initially, the public corporations took charge of everything from land acquisition to building uniformly designed apartments placed in parallel with each other. In the 1970s, private developers were allowed to participate in the project, as the focus of housing policy shifted from quantity to quality. The private developers assimilated the systematic know-how of public corporations and added diversity to public housing.

Conventional houses

A small number of traditional wooden houses typically built by small local builders are still in demand. Nowadays, even these houses tend to employ standardized housing components.

Prefabricated houses

Prefabricated house makers emerged in the mid-1950s, capitalized by steel, chemical and timber industries. Incorporating the production and marketing know-how of electrical appliance and automobile industries, the prefabricated house market grew steadily, with annual production reaching 250,000 units today. Leading prefabricated house makers are conducting business on a scale comparable to that of major construction companies. In response to diversifying customer needs, the house makers have adopted IT systems to flexibly update their catalogs and showrooms.

3. Diffusion of Low Energy Apartment Buildings

○ Efforts by the Urban Renaissance Agency

- Regarding the older apartment housing stock that was built on a uniform design and positioned in parallel with each other, the per unit energy efficiency may not significantly improve even if thermal insulation and double-pane glass windows were added.
- As the focus of government's "sustainable public housing" policy is on improving existing housing stock rather than constructing new houses, the priority is on recycling housing assets (e.g., through diversification of standardized housing units and replacement of components, etc.) rather than on saving energy.
- As a result, the current focus of public housing is on renovating existing apartment complexes along with adoption of energy-efficient heating and air-conditioning equipment.
- Renovation of apartment complexes to increase greenery and the use of renewable energy is essential to making urban life more sustainable.

4. Diffusion of Low Energy Buildings in the Prefabricated Housing Market

○ **Supply of low energy housing units by leading prefab house makers (2007)**

Sekisui House: 19,000 units
Daiwa House: 11,000 units
Sekisui Heim: 12,000 units
Misawa Home: 10,853 units
Total: 53,000 units (about 1/3 of all prefabricated housing units in Japan)

○ **Low energy offerings from prefab house makers**

Sekisui House	Daiwa House	Sekisui Heim	Misawa Home
Kyoto Protocol compliant	xevoE	Zero heating/lighting cost house	Zero energy house
Customizable designs Recycling service	Customized plans	Comfortable life Recycling service	Standardized houses
High thermal insulation	High thermal insulation (with proprietary technology)	High thermal insulation	High thermal insulation
All electric	EcoCute Heat pump system	EcoCute Heat pump system + Energy-efficient heating and air-conditioning equipment	Option ENE・FARM (fuel cell system)
Solar powered (with solar roof tiles)	Solar powered	Solar powered	Solar powered

○ Sekisui House offers custom designed houses for high-income customers.
○ Daiwa House offers customized houses with proprietary thermal insulation technology.
○ Sekisui Heim offers highly manufacturable box units with energy-saving

technology

○ Misawa Home supplies customized houses built with the timber panel method.

5. Summary -- Low Energy Housing Promotion Policy in Japan

○ Increased environmental awareness of the general public will serve as the "market pull." (e.g., Toyota Prius)

○ The Comprehensive Assessment System for Built Environmental Efficiency (CASBEE) will serve as the "industry push."

○ The national strategy for environmental protection entitled "Cool Earth" will be implemented at government agencies, giving a boost to similar efforts in the construction industry.

○ Ongoing trends in the housing market:

- The focus of construction policy is shifting from reuse of housing stock to building sustainable houses.
- Systematic compilation and commercialization of know-how on renewable architectures is making progress. (Fig.)
- In response, the efforts to renew apartment complexes as viable commercial enterprises are gaining support.
- The Apartment Renewal Support Association will be established as the first step toward implementing the apartment complex renewal project.

Energy efficiency and new building concepts in industrial building process

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Abstract

Traditionally the Finnish legislation has been focused on energy use and especially on space heating energy use of buildings. However, often this does not lead to the optimal concept in respect of minimizing green house gases. This paper studies in which way CO_2 emission levels are affected by different measures to reduce energy consumption in buildings. The paper presents real apartment buildings with different options of energy efficiency and power sources. The paper is limited only to building level and not considered all aspects of built environment and infrastructure. This paper also considers the electricity used for HVAC equipments thus, the user electricity, which is always the major source of electricity consumption, is not considered. Thus the source of electricity has much higher influence on CO_2 emissions than this paper presents.

The calculations showed clearly that in the future electricity and domestic hot water use has a high importance in respect of energy consumption and therefore also CO_2 ekv. emissions. The importance increases as the energy efficiency of the building increases. There are big differences between average Finnish production and single power plants e.g. the CO_2 ekv. emissions might nearly double depending of the energy source and power plant type. Both a building with an efficient district heating as a power source, and building with ground heat in addition to nuclear power electricity as a complimentary electricity source performed very close each other in respect to CO_2 ekv. emissions. But to make from this a conclusion that it has no importance which alternative we choose is dangerous. If hypothetically the use of district heating would drop dramatically, that would mean than the primary energy factor and CO_2 ekv. emissions from electricity would rise clearly which would the lead to the increase of the ground heat systems emissions. Problem in the yearly calculations are always that we exclude the fact that it is also very important, sometimes even crucial when energy is needed.

Keywords: Energy use, energy source, new concepts

1. Introduction

The built environment has a large impact on the natural environment, economy, health and productivity. Buildings account 17% of the world's fresh water with drawls, 25% of the wood harvest, 40% of materials and energy flows and 30-40% of all primary energy used. Over 80% of our harmful emissions are due to energy consumption.

Energy efficiency is one of the important factors in order to reduce buildings harmful emissions to environment. Traditionally in Finland our regulations e.g. building code gives minimum criteria for U-values and ventilation heat recovery, which is obviously important way to reduce heating consumption. However, if the heat source for heating is district heating, saving heat do not save that much environment in the sense of CO_2 emissions. Electricity use in buildings is until now very little regulated in Finland even though the consumption is all the time increasing and the heating decreasing as Figure 1 shows.

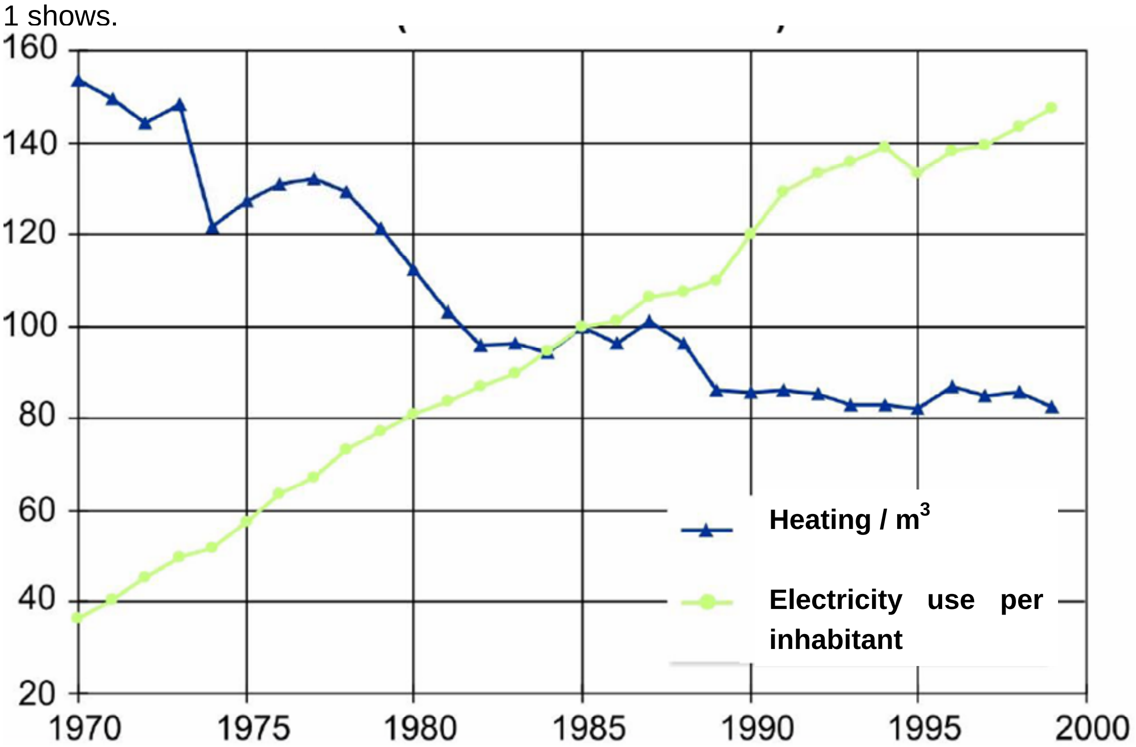

Figure 1. *The history of building electricity and specific space heating consumption [1]*

Due to reasons mentioned earlier, it is evidently very important not only to minimize energy consumption but in addition to choose the less polluting energy source. That isn’t easy task either. Harmful can be green house gases, toxins to water systems or ground soil. Also how long we should follow the path from consumption to energy source can be hard to decide. Due to very complex nature of this question we limit our calculations only for building energy consumptions CO_2 equivalent emissions.

2. Methods

The buildings studied were two Skanska's apartment buildings (Gardenia and Satamawouti) in design phase. In order to compare buildings easily, the buildings in this study were assumed to be located in capital area. Both buildings were in design phase and the aim was to study the best alternatives to reduce green house gas emissions. Three levels of energy consumption in both buildings were calculated. The basic level was today's building code (BC 2008). Two other levels were the Finnish building code level 2010 and assumed building code level 2012. The used properties in the calculations are shown in Table 1.

Figure 2. *The studied buildings*

Table 1. *Used properties in calculations*

	BC 2008		BC 2010		BC 2012	
	Gardenia	Satamawouti	Gardenia	Satamawouti	Gardenia	Satamawouti
Envelope air tightness n_{50} (%)	4	4	2	2	1	1
Ventilation heat recovery (%)	30	30	50	50	70	70
Air change rate (1/h)	0.7	0.5	0.7	0.5	0.7	0.5
Roof (W/m^2K)	0.16	0.16	0.09	0.09	0.09	0.09
Exterior wall (W/m^2K)	0.24	0.24	0.14	0.14	0.14	0.14
Base floor (W/m^2K)	0.2	0.2	0.14	0.14	0.14	0.14
Window (W/m^2K)	1,3	1,4	1	1	1	1
Balcony door (W/m^2K)	1,4	1,4	0.07	0.07	0.07	0.07
Door (W/m^2K)	1,8	1,4	0.07	0.07	0.07	0.07

The used COPs for ground heat pumps is 3.5 for space heating and 2.7 for domestic hot water. Due to cold Finnish climate it was assumed that 15% of the time heat pumps can not supply all heat needed and therefore extra power was needed. That power was either assumed to be from nuclear power plants or coal plants. CO_2-ekv emissions from electricity and district heating were calculated from the average emissions in Finnish power plants. However, e.g. the Helsinki city energy production company, Helen, gives lower values; 120 gCO_2/kWh for district heating and 260 gCO_2/kWh for electricity in combined production. This was also used in the calculations as a one case example for showing how different the combined district heating and electricity power plants can be in the sense of CO_2 equivalent emissions and primary energy.

Table 2. *Used primary energy factors and CO_2ekv emissions in the calculations [2]*

	Primary energy factor -	**CO_2 ekv** kg CO_2/kWh
District heating average	1.87	220
District heating Helsinki	0.4	120
Electricity average	1.87	380
Electiricity from district heating average	1.87	380
Electiricity from district heating Helsinki	2.5	260
Peak electricity from nuclear power	2.8	0
Peak electricity from coal	2.0	928

3. Results

3.1 Heat losses

The heat losses were dominated by ventilation and windows, who accounted 65-75% of the losses depending of the case, Figure 3. Even though the buildings were different in shape and occupied roughly same amount of window are per floor area, there was not a clear sign that the combined form in shape would give much benefit. However, both buildings were compact in shape and efficient in the sense of heat losses.

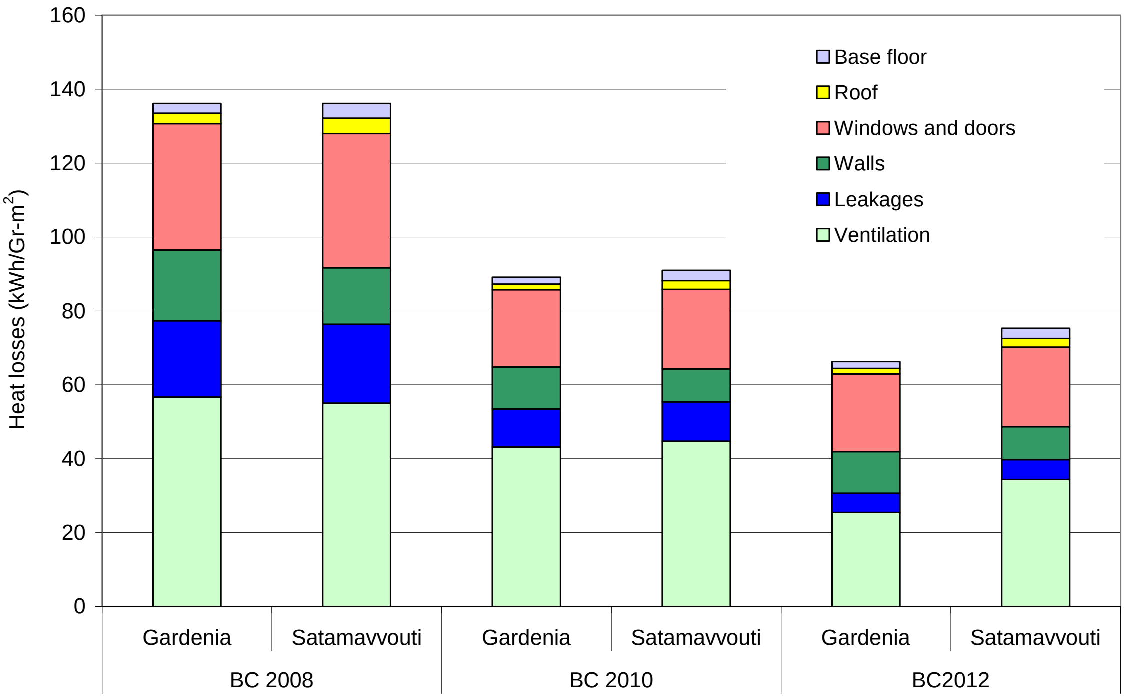

Figure 3. *Heat losses in different studied cases.*

3.2 Energy consumption

When the energy consumption is considered, it can be clearly seen, that the space heating is dominated in buildings constructed according today's building code (BC 2008), but in the near future the domestic hot water has the major influence, Figure 4. Due to *Legionella* and other hygienic reasons the domestic hot water needs to be heated at least 60°C. In order to use low temperature heat sources that is giving an extra challenge and might lead to higher costs.

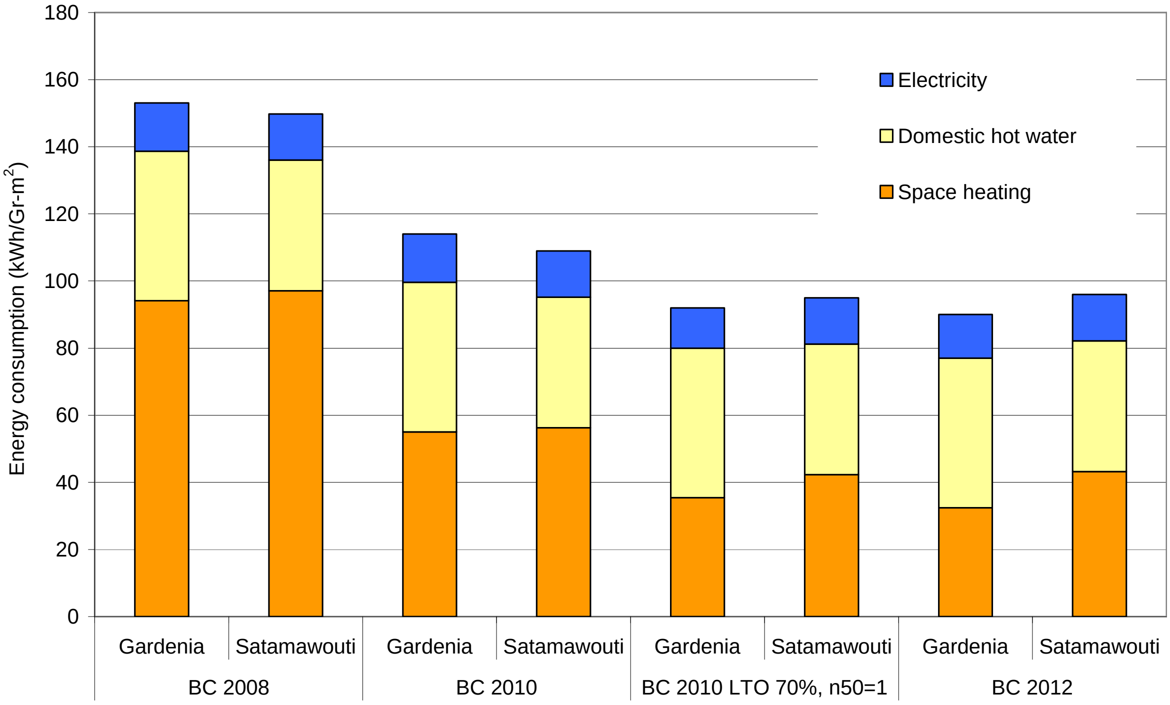

Figure 4. *Energy consumption in different cases.*

As already mentioned, the share of electricity consumption is only the electricity used for HVAC and corridor lightning. When the user electricity is taken into account the share is much higher. Since the energy consumption levels with BC 2010 level but higher ventilation heat recovery (70%) and building envelope air tightness, and BC 2012 level are rather close, in the following calculations only the BC 2012 level is shown.

3.3 Primary energy consumption

As well known district heating is an efficient way to produce electricity and heat. In the calculations both average Finnish district heating primary energy factor was used but also as a case example one specific power plants (Helsinki) factors was used in order to see the difference from average. The district heating used from efficient combined plant (in this example Helsinki Energy) gave lowest primary energy consumption,

Figure 5. Direct energy used clearly most primary energy, but it should be noted that also in electricity there are huge differences between power plants and energy sources. Electricity can be produced from renewable sources as well.

In the area where district heating already exists the ground heat uses clearly more primary energy compared to both alternatives in district heating if the same electricity power plant is used. However, ground heat is rather close to average district heating especially when the energy efficiency of the building is higher (levels 2010 and 2012). Since in the coldest days ground heat needs supporting power two cases for peak power are calculated; nuclear and coal power plants.

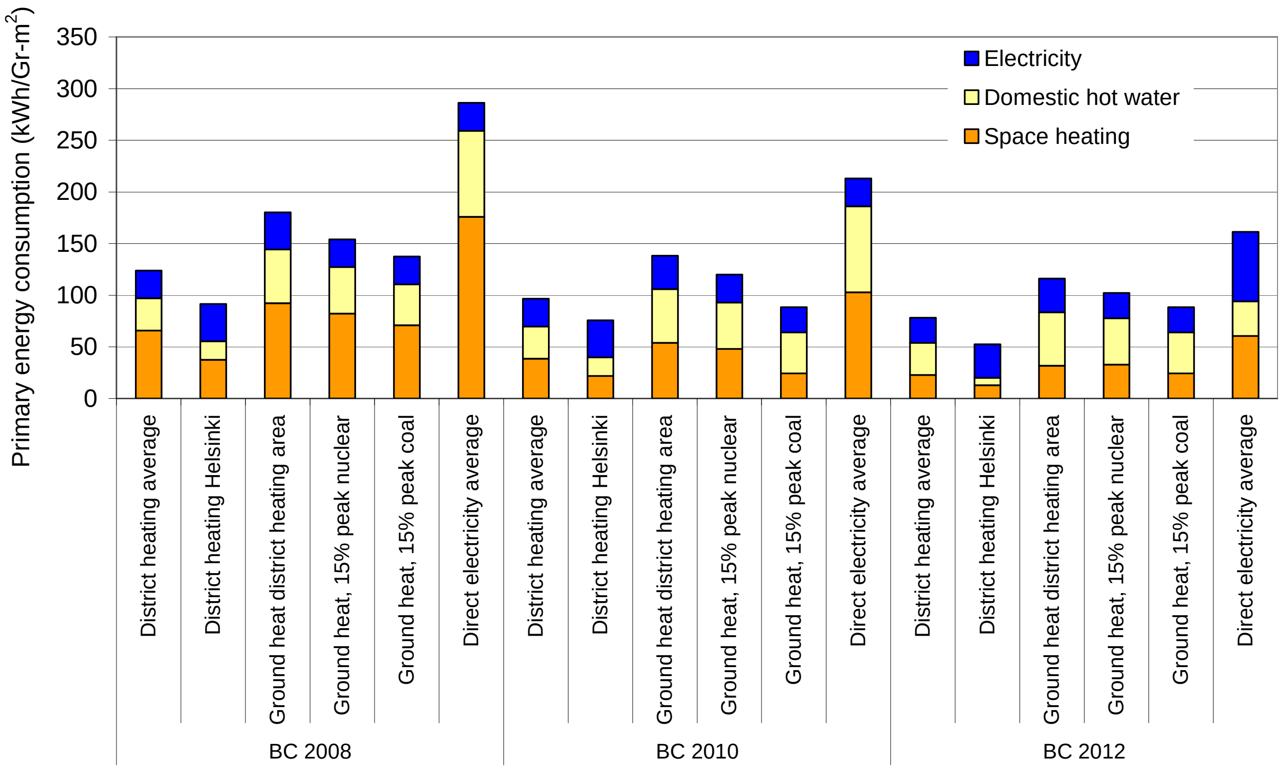

Figure 5. *Primary energy consumption in different cases.*

3.4 CO_2 equivalent emissions

Basically primary energy calculations give us the big picture of CO_2 ekv. emissions as well. However, the big exception to that is electricity produced from nuclear power since that energy source has a high primary energy factor but nearly no CO_2 ekv. emissions. The emission calculations were interesting since it showed that efficient district heating as a power source and building with ground heat in addition to nuclear power electricity as a complimentary electricity source performed very close each other, Figure 5. But to make from these numbers conclusion that it has no importance which alternative we choose is dangerous. If hypothetically the use of district heating would drop dramatically, that would mean than the primary energy factor and CO_2 ekv. emissions from electricity would rise clearly which would the lead to the increase of the ground heat systems emissions.

Again, Figure 5 shows that electricity and domestic hot water use has a high importance in respect of CO_2 ekv. emissions and the importance increases as the energy efficiency of the building increases.

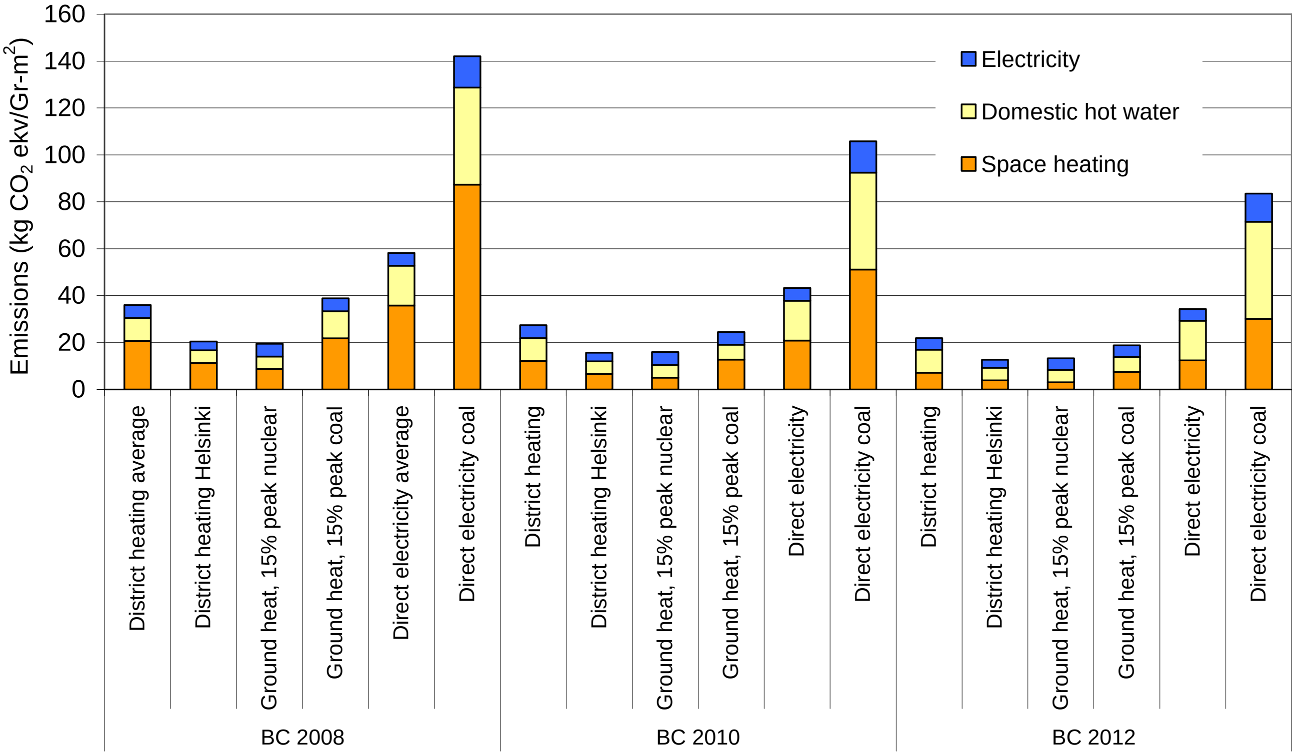

Figure 5. *CO_2 ekv. emissions in different cases.*

4. Discussion and conclusions

In the future electricity and domestic hot water use has a high importance in respect of energy consumption and therefore also CO_2 ekv. emissions. The importance increases as the energy efficiency of the building increases. When renewable energy sources are used they typically have lower temperature levels. That is very complicated in respect of domestic hot water heating since it needs to be heating up to 60^{o}C due to *Legionella* and other hygienic reasons.

There are big differences between average Finnish energy production and single power plants e.g. the CO_2 ekv. emissions might nearly double depending of the energy source and power plant type.

Both a building with an efficient district heating as a power source, and building with ground heat in addition to nuclear power electricity as a complimentary electricity source performed very close each other in respect to CO_2 ekv. emissions. But to make from this a conclusion that it has no importance which alternative we choose is dangerous. If hypothetically the use of district heating would drop dramatically, that would mean than the primary energy factor and CO_2 ekv. emissions from electricity would rise clearly which would the lead to the increase of the ground heat systems emissions.

Problem in the yearly calculations are always that we exclude the fact that it is also very important, sometimes even crucial when energy is needed. An example of that might be ground heat solutions used in buildings which can not serve in very cold days but need typically supportive power in those days. In respect to emission that can be problematic if the extra power supplied to markets is produced with a polluting energy source. On the other hand in the buildings were cooling in needed ground heat has the advantage that it can be used during cooling periods as well.

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Low energy buildings - crucial factors in industrial process

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Abstract

Due to the raise of energy and environmental issues low energy buildings are becoming more and more popular. Building process is a team work and can only perform as good as the weakest link is. Therefore it is extremely important that already in the early design phase all the important aspects' regarding energy use but also the practicality and details are considered deeply enough in order to guarantee that no unpleasant surprises occur later in the process. This paper discusses the most important factors in respect of industrial process.

Keywords: Energy use, new concepts, indoor air quality

1. Introduction

Residential and commercial buildings account for 40% of all energy used in Finland, in addition commercial and apartment buildings have a notable influence on the peak demand in some periods. Energy and electric intensity in commercial buildings has increased clearly, and residential energy use especially electricity use continues the increase. Yet technologies and knowledge exist, that could be used to create better, high-performance buildings. In fact, combined with better systems integration, they could cost-effectively achieve savings as high as 30% in new buildings, as compared to minimally code compliant structures. Existing retrofit technologies and retro-commissioning practices could provide economically efficient additional energy savings in existing buildings.

Traditionally the design, construction, and/or operation practices used to be, and in many cases still are, rather fragmented. That is the major barrier to allow the timely and effective implementation and integration of energy efficiency methods and technologies on every new building and renovation project.

In the worst case main criterion for decision making about design alternatives are cost and aesthetics. Therefore, unfortunately in many cases decision making in early project phases, when the influence on overall project performance is largest, is mostly based on what can be seen (aesthetics) and what can be quantified relatively easily (initial cost). This process minimizes cost at every step, but does not describe when and how to consider other criteria, such as energy concerns and end-user needs, and thus limits the incorporation of such lifecycle knowledge into the planning and design process in a consistent, predictable, and valuable way; the incorporation of methods and technologies for energy efficiency comes often as an afterthought.

Due to challenges mentioned above in the construction field Skanska has already many years worked systematically and developed guides for the holistic integration of the building process from the early design phase up to building use. United Nations (UNEP) has adopted the facility managers guide for their facility managers as well in co-operation with Skanska [1].

2. Methods

This study is combines and highlights the important results of several development projects from Skanska's industrial construction process.

Skanska has developed a guide for its facility manager to help the energy and eco efficient management for buildings. The purpose of the guide is to empower facilities managers to increase the energy efficiency of the buildings, whether owned or leased; and to signpost facilities managers to the key information sources on energy efficiency and renewable energy, including the support programmes.

This article also considers some of the best practice examples and important aspects in building process in order to gain energy efficient buildings in the long therm.

3. Results

Building process is a team work and can only perform as good as the weakest link. Therefore it is extremely important that already in the early design phase all the important aspects' regarding energy use but also the practicality and details are considered deeply enough in order to guarantee that no unpleasant surprises occur later in the process.

3.1 Design phase

Usually in the beginning of a building development project we know very little about the users, thus, the process needs to be flexible in order to fulfil clients' needs in the future. The paradox is that in the early pre-design phase we have very little information but need make the most important decisions about the energy efficiency and sustainability of the building. In order to make the right decisions Skanska has developed a guide including target values for energy consumption, structure properties etc. It is also extremely important that an energy expert is involved in the early phase.

Building air tightness has a clear influence on energy consumption which is often neglected or not remembered. Compared to today's building code level (n_{50} = 4 ach) we can save more than 10 kWh/m^2 only by doing a careful work on site, Table 1.

Table 1. *Reduction in energy consumption with airtight building envelope*

Air tightness n50, 1/h	Reduction in energy consumption [kWh/m^2]
4	0
3	-3,85
2	-7,5
1	-10,9
0,5	-12,46

3.2 Construction phase

However, building air tightness does not only influence on energy consumption but also on thermal comfort. Air leakages are always also risks in respect of moisture and possibly mould. Therefore developing air tight buildings has been one of Skanska's priorities in construction at site. The most important actions needed are careful work when joining structures together and usage of pre-fabricated penetration parts. Typically the joints in windows and doors are the major leakage source as also a recent study of Tampere University of Technology shows, Figure 1.

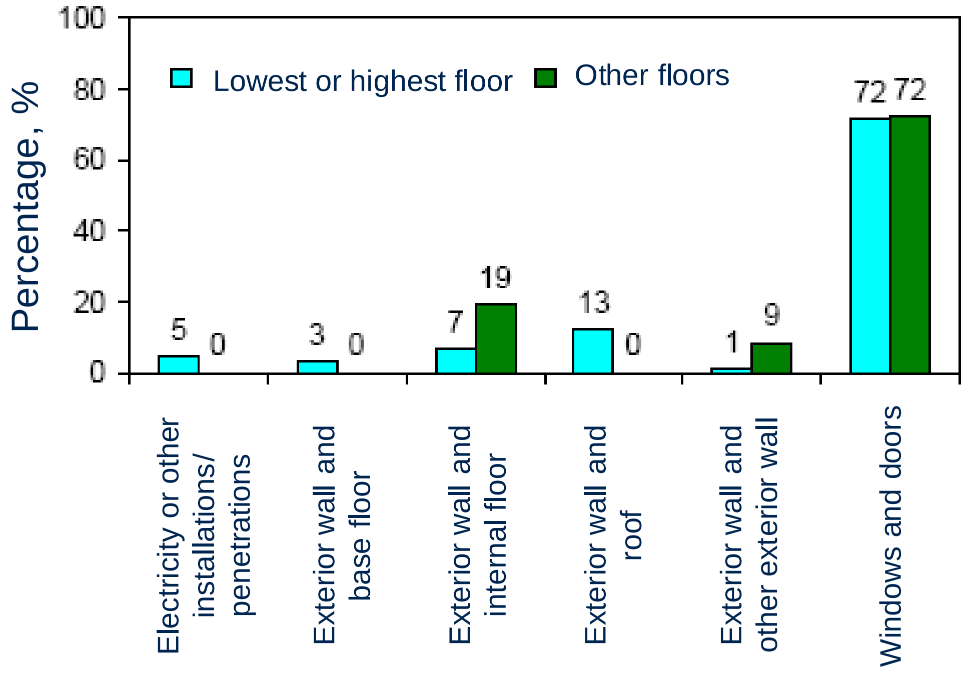

Figure 1. *Air leakage location in apartment buildings [2]*

Pressure difference over the exterior walls is always a challenge in buildings with many floors, as the typical case is in apartment buildings. In addition to building height also wind and temperature have a major influence on pressure difference across the exterior walls. Even though the ventilation system is adjusted and measured well in the building handover, the situation is completely different in the first cold days. The pressure difference across the envelope can be as high as 20 Pa during winter, Figure 2.

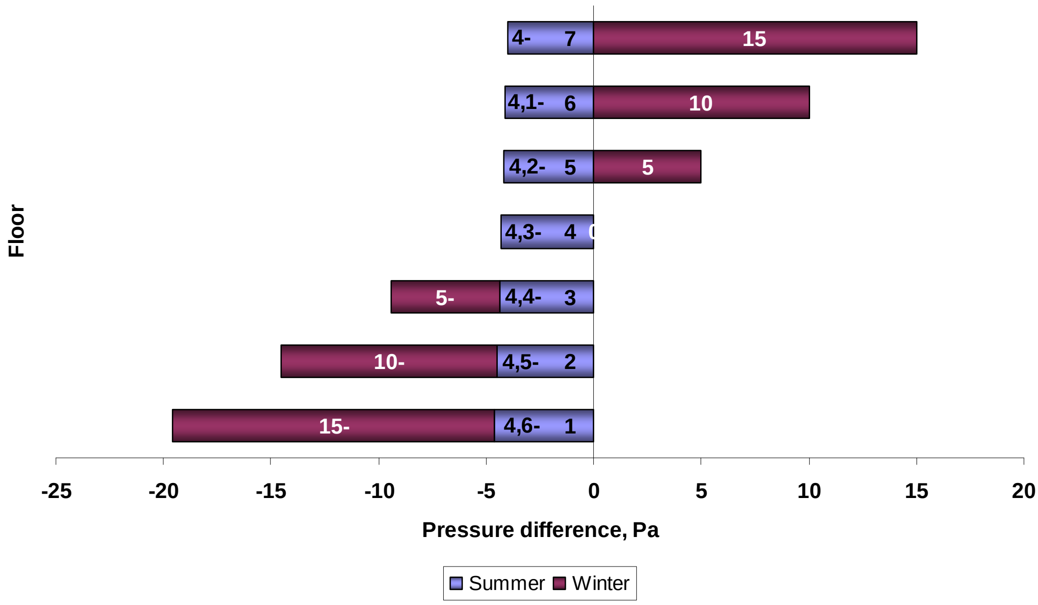

Figure 2. *Pressure differences in one seven floor apartment building during winter and summer time. The ventilation system was adjusted during summer period.*

In addition to sustainability and energy efficiency also indoor air quality is very important in respect of clients comfort and health. Therefore Skanska has systematically developed construction process in order to minimise the emissions indoors and also to guarantee that the emissions levels are not only according to building code level but in the level lowest possible when the inhabitants move in, Figure 1. This is a continuous process since building materials are changing constantly thus also the emissions indoors.

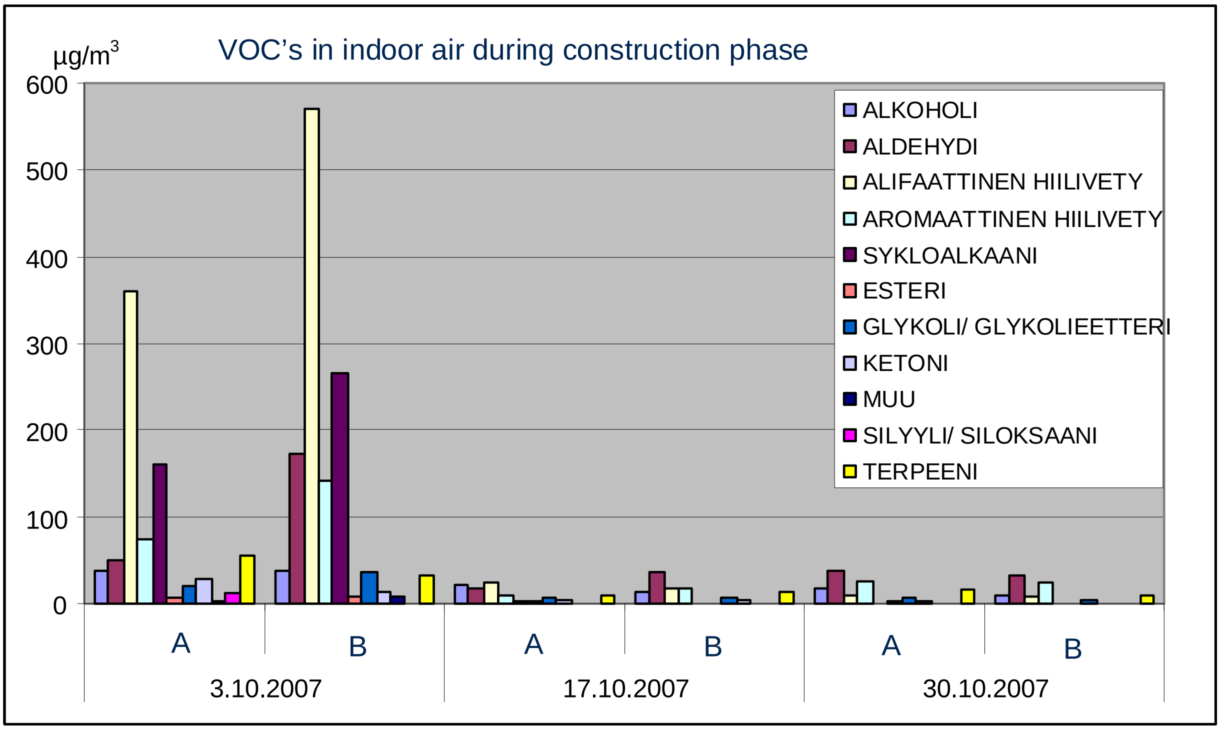

Figure 2. *The decrease of VOC's concentrations in indoor air during construction phase [3]*

3.3 Energy consumption of building users

The energy consumption of different families and individuals vary a lot. In today's buildings the difference can be roughly +- 30%. In the future, when energy efficient buildings are common, the proportional difference will increase even tough the absolute is smaller. This is because all misuse has a higher importance if the baseline consumption is low. Most probably this will lead to a development where energy consumption is measured (and paid) in every single apartment. Also the importance of distant control and "alarm" for too high consumption might be more common in the future.

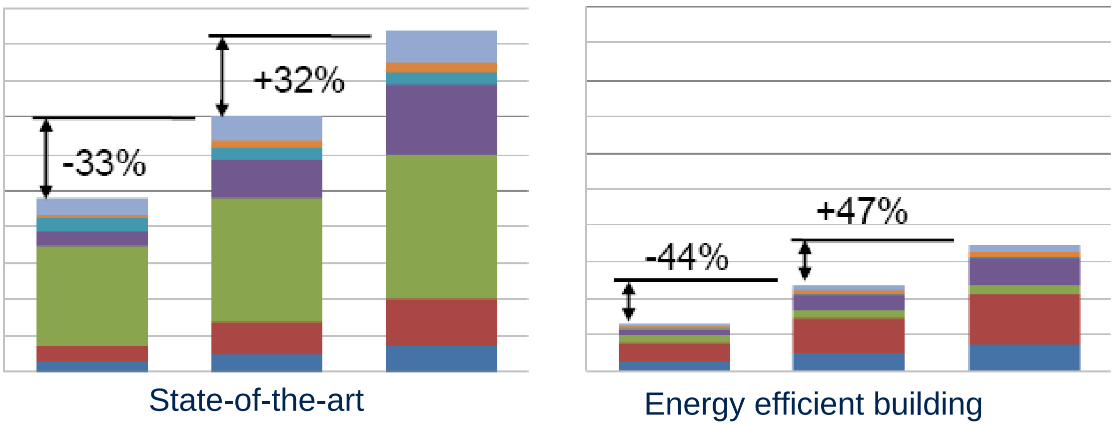

Figure 3. *The percentual difference between energy consumption of individual apartments will be higher in the future. However, the absolute differences are obviously smaller.*

In general people are rather well informed and interested about energy saving. Majority wants to save energy, but often they do not know when and how appliances at home and work are consuming energy.

3.4 Facility management

Energy efficiency is not only good design and careful construction. The key to energy efficiency is management – it doesn't matter how much it is spend on technology, without management the money will be wasted. Energy efficiency should be thought as a continuous process, Figure 4. Measurement, even a basic one e.g. base on energy bill, is the first step. Without the fact how much energy has been used, it is not possible to save it.

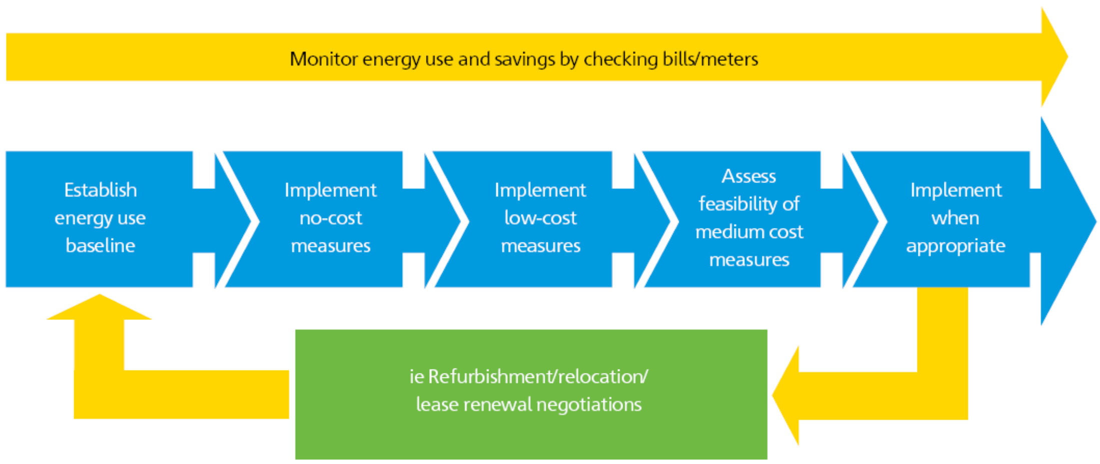

Figure 4. *Energy management decision process*

Without establishing the current energy use, no saving can be made. In old facilities that can be as simple as check bills, but in newer ones with advanced distant control units. Next step is to find out the easiest ways to save energy (and money) and then to evaluate what is the target we want to achieve and want are the necessary and cheapest ways to achieve the goal. One simple list can be seen above [1]. It is also important to understand that the facility management and energy saving is a continuous process.

Table 1. One example of a check list for facility manager

1 No cost – Establish current energy usage and check bills to make sure you are on the right tariff

2 No cost – Incorporate energy efficiency into maintenance activities

3 Low cost – Exclude draughts

4 Low cost – Increase the energy efficiency of water heating systems

5 No cost / Low cost – Improve the efficiency of air conditioning / ventilation systems

6 Low cost – Improve the efficiency of lighting systems

7 Low cost - Install or top up loft / roof space insulation

8 Medium cost – Insulate walls

9 Low cost – Increase the efficiency of space heating systems

10 Medium cost – double or triple glaze all windows

4. Discussion and conclusions

Building process is a team work and can only perform as good as the weakest link. Therefore it is extremely important that already in the early design phase all the important aspects' regarding energy use but also the practicality and details are considered deeply enough in order to guarantee that no unpleasant surprises occur later in the process.

Skanska has developed systematically guides for all process phases and one of the most recent one is the facility managers guide, which is adopted also by UNEP.

The most important single aspects in respect of energy efficiency are pre-design phase, careful details, low emitting materials and good indoor climate, users knowledge and guidance of energy efficiency and facility management.

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The Contribution of Solar Energy to Low Energy Building Concepts for New Buildings and Renovation

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Abstract

Buildings account for more than 40% of energy consumption and renovation of existing building takes up up to 80% of today's market. The integration of solar systems plays an important role to reduce emissions from this sector.

Low load bearing industrial roofs make up a large area of currently unused space, which could contribute to emission savings if made available for PV systems.

As traditional PV systems – framed in glass and tilted, which increased the weight by incurring wind loads – are often too heavy for such roofs, Solar Integrated has developed lightweight PV products making low-slope industrial roofs accessible for solar energy generation.

For example, our Solar Membrane Roofing, consisting of traditional roofing membrane with integrated PV elements, adds only 4,9kg/m² to the weight of a roof. Due to its complete and parallel fixation no additional wind loads are generated.

The thin film PV technology employed produces high energy yields even if installed nearly flat and is rarely affected by increasing module temperatures – important for building integration.

In a case study based on an existing system the roof installation as well as the energy generation and emission saving benefits of a PV system will be explored in detail.

Keywords: photovoltaic, energy generation, emission saving, renewable energies

1. Introduction

The international goal agreed to in the Kyoto Protocol is to prevent global temperature rise above 2°C of pre-industrial conditions to avoid immeasurable changes to the globe and human society.

Reducing energy consumption, reusing energy already available and creating smart energy systems combined with electricity production from clean energy sources can have a huge impact considering that buildings account for more than 40% of all energy consumption. However these measures need to be applied on a broad scale from family homes to factories, shopping malls, schools, hospitals and logistics centers if the effect is to be sustainable and not a simple show of good will.

This paper explores the potential of making currently unused space on low-load bearing industrial, commercial and institutional roof-tops available for solar energy by developing a lightweight, easy-to-install, durable product that generates high energy yields.

2. Background

Sustainable development has become an urgent necessity to maintain a stable climate, secure long-term energy supply and improve health and well-being of the global population.

2.1 Stable Climate

Climate changes lead already today to an increasing number of natural catastrophes, be it rising ocean levels, threatening coastal regions as in Bangladesh or on the Pacific islands; more and stronger tornados and hurricanes, leading to vast destruction of human, animal and floral habitats or flooding in some areas and desertification in others.

Apart from the physical and psychological devastation such disasters incur increasing costs for making up of damages, putting a burden on every society and its members. As this burden will not be easily carried by many nations increasing levels of social and regional instability and conflicts over resources could be the result.

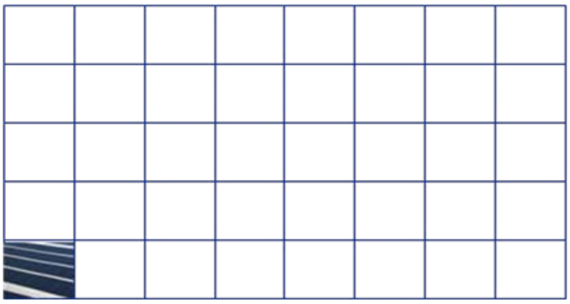
2.2 Energy Supply

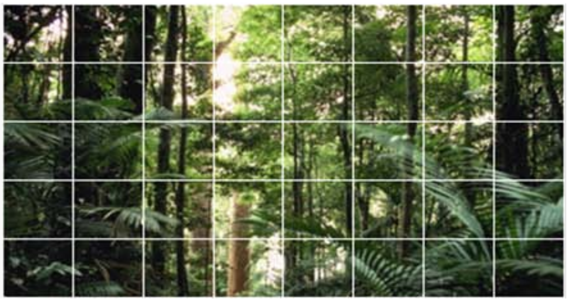
The global energy demand today is served by oil (34%), coal (24%), gas (21%), biomass energy (11%), nuclear power (7%), hydro power (2%) and other renewable energies (1%). Verified and economically accessible reserves, however, are expected to last for a short time only. Coal 93 years, gas 68 years, uranium 65 years, oil 40 years and crude oil 15 years. This implies a pressing need for developing alternative energy resources such as wind, bio-fuel, geo-thermal, solar-thermal and photovoltaics. [1]

2.3 Health and Well-Being

Reducing emissions automatically improves air quality as could be "clearly" observed during the Olympics in Peking, where outdoor games were only possible after numerous factories surrounding the city stopped production and automotive traffic was drastically reduced.

As an example, a 200 kWp photovoltaic system produces up to 262 MWh of electricity per year. Over a period of 30 years it saves approx. 7000ts of CO_2 emission. To balance the CO_2 emission generated by producing the same amount of energy by fossil fuels would require planting a forest of 7.000.000 m2 – equivalent to 980 soccer fields.





Space required by the solar system

Space required for a forest to balance the CO2 emission of fossil fuel energy

2.4 General Benefits of Sustainable Design

In addition to being a necessity sustainable design in general and the integration of photovoltaic system into new and existing buildings also offer substantial benefits to the individual investor.

These are competitive advantages due to increasing customer interest in environmentally friendly products and practices, strengthened brand reputation because of increased credibility, shareholder value and access to good investors, and finally higher identification and motivation of employees. [2] [3]

2.5 Monetary Benefits of Photovoltaic Systems

The most direct advantage of integrating photovoltaic systems into building concepts is that if offers a direct monetary advantage in terms of cost reduction or revenue generation, depending on the availability of governmental incentive schemes (e.g. feed-in tariffs) and public grids to feed into the power produced from the PV system. In case one or the other is not available on-site use of the produced power reduces the overall electricity costs, particularly at peak-times, where energy costs are highest as is solar energy production.

In most European countries the option of choice will be to feed the power produced from one's PV system into the public grid to take advantage of existing feed-in tariffs. A feed-in tariff usually allows to selling kWh produced at a higher price than kWh bought from the utility. The level of the feed-in tariff rates is usually fixed for a certain time period, e.g. 20 years and that way guarantees a stable rate of income and – if the solar system performs as planned – a guaranteed return on investment. This makes investments into photovoltaic systems especially attractive during the current financial crisis.

3. Solar Technology – A Brief Overview

A solar or photovoltaic module is the main component of a grid-connected photovoltaic system. Other components are mounting structure, wiring, inverter to convert direct current into alternating current and options like energy meter, monitoring system etc.. The main differentiator of PV module technology is whether the photovoltaic cells are made from crystalline silicon or in a thin-film coating process.

3.1 Crystalline Silicon Cells

Crystalline silicon cells can be divided into mono-crystalline and poly-crystalline cells. Mono-crystalline cells are made from a solid mono-crystal, in which the lattice of the entire cell is without grain boundaries. Mono-crystalline PV cells are considered to render the highest efficiency due to the pureness of the material.

Poly-crystalline cells are a solid material composed of many crystallites of varying size and orientation. Poly-crystalline cells can be recognized by visible grains, a "metal flake effect".

Crystalline silicon photovoltaic cells are extremely fragile and sensitive to humidity. Therefore they need to be protected against breakage and humidity by an encapsulation into EVA (Ethylene-Vinyl-Acetate) with glass towards the sun-light and usually Tedlar as a back sheet. These PV modules are installed tilted on a substructure for optimal energy generation.

3.2 Thin-Film Cells

Thin-film solar cells or modules vary according to their composition and substrate material. They are coated with amorphous silicon or other photovoltaic material like copper-indium-diselenide (CIS) or cadmium telluride (CdTe). The range of their physical characteristics and performance depends on the material. Due to the thin layer of active material coated onto a substrate, the material input required is much lower than for crystalline cells (100 – 300 µm compared to 0,2 – 5 µm).

Amorphous silicon thin-film modules
An amorphous silicon solar cell (a-Si) is made when silicon atoms are deposited to a substrate material. During solidification the atoms cannot connect to other atoms and hence remain disordered without a crystalline structure.

Deposition can be performed onto rigid or flexible substrates. By an intelligent selection of the encapsulation material the flexibility of the solar cells can be maintained when hence flexible modules can be build. These can be applied to flexible substrates.

4. Traditional PV Systems

4.1 Weight

Traditional PV Systems – be they made from crystalline silicon or thin-film cells – are packaged in glass and set up tilted in a 30° angle on the roof facing south.

Due to the weight of the glass and the substructure the weight of such PV systems often reaches 25 kg/m^2 or more. Because the system is propped up, additional wind-loads need to be taken into consideration, which can increase the total accountable weight load by more than ten times the module weight.

On the other hand, however, large roof-tops of e.g. warehouses, distribution centers, shopping malls or sport stadiums, are seldom designed to carry heavy additional static loads for cost reasons, but are often restricted to a maximum of a further 10 kg/m^2 – making these large roof areas unavailable for solar power generation.

4.2 Area Usage

Particularly traditional crystalline silicon PV systems generate the most energy during midday, optimally aligned towards the south, propped up in a 30°degree tilt angle. Under such circumstances a 91% energy yield is possible (module basis, not considering balance-of-system factors). With a south-west alignment the energy yield is instantly reduced to 87%.

Such set-up requires a certain spacing of the module rows to avoid self-shading. This reduces the theoretically level of area usage to 33%.

Due to the relatively high efficiency of crystalline silicon cells, the low area usage is usually ignored.

4.3 Efficiency versus Energy Output

Many companies focus on the module efficiency and nominal power when planning a solar system. Efficiency and nominal power (Pnom) of a PV module are measured under standard test conditions (STC) (1000 W/m2, AM 1.5, 25 °C Cell Temperature).

Experts agree that real world operating conditions vary greatly from standard test conditions, but have a much greater impact on the final energy output produced. Hence the expressiveness of the efficiency and nominal power to judge the performance of a solar system are misleading. The efficiency determines only the amount of space required to install a certain amount of nominal power. The nominal power is one single point of the matrix of power production conditions under real environmental conditions.

The brightness of the sun, latitude, and season, time of the day, air mass, cloud cover and pollution are factors influencing the energy rating of a photovoltaic system. Additionally, increasing cell temperature – impacted by ambient temperature, insolation and wind – influences energy production.

As all photovoltaic modules are specifically influenced by real world outdoor conditions, the energy rating (or energy yield) – i.e. the electricity generated in relation to the amount of kWp installed (kWh/kWp) – is the main indicator of the suitability of a particular solar system at a certain location.

Module Type	**Efficiency**	**Specific Energy (measured at the test side of the University of Urbino in Italy, tilt angle 30°) [4]**
Thin-film amorphous silicon (triple-junction technology by UNI-SOLAR®)	Approx. 6,5%	1064 kWh/kWp
Mono-crystalline silicon modules	Approx. 14 % on average	962 kWh/kWp (average of all mono-c-Si modules at the Urbino facility)
Poly-crystalline silicon modules	Approx. 12 % on average	936 kWh/kWp (average of all poly-c-Si modules at the Urbino facility)

Table 1, comparison of module efficiency and energy rating of different module types at the University of Urbino, Italy, test-site.

5. Solar Integrated's Approach

The introduction to this symposium mentions the need for sustainable building concepts to include high lifetime quality in relation to usability, economic, ecological and cultural aspects.

The Solar Integrated approach to develop and produce photovoltaic products for large low-load bearing roofs is based on comparable requirements.

5.1 Product Solution

One of the product solutions developed is the SolarRoof Membrane – a traditional roofing membrane with fused PV elements.

The SolarRoof Membrane translates the a.m. requirements of the Symposium on a sustainable building design into the following characteristics:

High lifetime quality = durability

Durable materials guarantee the long-term availability, low maintenance and related down-times of the PV system, even in severe conditions. PV modules normally come with a performance guarantee of 20 – 25 years. This implies that all material related to them and the roof construction should have a minimum lifetime of this time frame. As PV systems are capable to produce energy beyond this time a longer lifetime of the related materials is of advantage. The SolarRoof Membrane in its T2 version is based on a roofing membrane that has a lifetime of 40 to 60 years – allowing to take full advantage of the energy generating roof.

The thin-film amorphous PV technology from UNI-SOLAR® has been installed since more than 10 years and has been tested under severe conditions ranging from space, ocean to dessert applications.

Usability = easy to install and maintain

Easy to install means no specific tools or equipment is required to apply the modules to the roof. The SolarRoof Membrane is delivered in a rolled-up form and can be fixed to a membrane roof (TPO or PVC) by hot air welding – as is done with the roofing membrane without PV modules. The maintenance requirements of the PV system are low – basically an annual check-up and if necessary cleaning with clear water – though normally at a minimum of 3° tilt angle, the system is automatically cleaned by running-off rainwater.

Economic = high energy yields

High energy yields are possible due to the triple-junction technology of the amorphous thin-film solar cells employed. Triple-junction means the thin-film layer is coated onto a base substrate in a way that three specific semiconductor layers are formed. Every layer collects the light in a specific range of the light spectrum – i.e. blue, green and red. Blue light is dominant in the morning and afternoon of the day as well as when it is cloudy or overcast. This means, these PV cells collect light over a longer time period of the day. Furthermore the triple-junction technology makes these PV cells less sensitive to orientation and tilt angle – allowing to install them nearly horizontally on an industrial roof.

Because the amorphous silicon cells have also a very low temperature coefficient, they are less affected by rising module temperatures, do not need ventilation or cooling and are hence ideally suited for building integration.

Ecologic = lightweight

Lightweight PV modules such as the SolarRoof Membrane allow the integration of solar energy systems into large building designs with limited additional load-bearing capacities and hence increase the area and number of buildings available to clean energy generation. Lightweight PV modules are made possible by the combination of traditional roofing membranes with flexible thin-film photovoltaic modules. The weight is reduced by the material – particular by the lack of heavy glass and metal frames and by the roof parallel application. This application form does not generate additional wind-loads, which add to the weight impact of photovoltaics. Hence, the SolarRoof Membrane adds only 4,9 kg / m² to the static load.

Cultural aspects = building integration

Considering cultural aspects when planning a solar system into the design of a building usually means **not** to place the PV system in the focus of the viewer, but concentrating on the structural elements of the building. By integrating the solar system into the building it becomes a part and melds into the appearance of the building. The SolarRoof Membrane can either "disappear" from view, when installed on a flat roof, or be used to pronounce a specific roof contour as it can adapt to bend shapes due to its flexibility.

5.2 Application Examples

Warehouse buildings in the port of Mannheim, Germany

A shopping center in Sta. Olivia, Spain

A soccer stadium in St. Gallen, Switzerland

A parish hall in Bösingen, Switzerland

6. Case Study

In the course of necessary re-roofing of apartment buildings in Rüsselsheim, Germany, the owner decided to increase its property value by adding a solar system. Due to the flat membrane roofs the SolarRoof Membrane was the module of choice.

The specific installation has a size of 44 kWp and started operation on 20^{th} of May 2006.

6.1 Initial Calculations

Based on the initial calculations the investment decision was made. In these the energy output was forecasted to be 37 MWh per year with a specific annual energy yield of 852 kWh/kWp.

The system saves 33ts/a of CO_2 emission.

6.2 Installation

Apart from the electrical parts, the SolarRoof Membrane is basically installed in the same way as a roofing membrane without PV.

The SolarRoof Membrane is coiled a cardboard tube and lifted by a crane from the truck onto the roof. There it is simply rolled right onto the roof.

A module can easily be handled by two people and is placed in its final location.The SolarRoof Membrane is then bonded by hot air welding to the new or existing roofing membrane, using exactly the same tools. For installation reasons it is possible to tread on the module – however, the soles shall be soft, clean and no sharp objects shall be scratching the module surface.

The cables are covered by a piece of roofing membrane, which protects them against the weather and corrosion, while leaving them easily accessible for maintenance purposes.

Finally the PV installation is connected to a converter, which converts the direct current produced into alternating current, which can be fed into the grid.

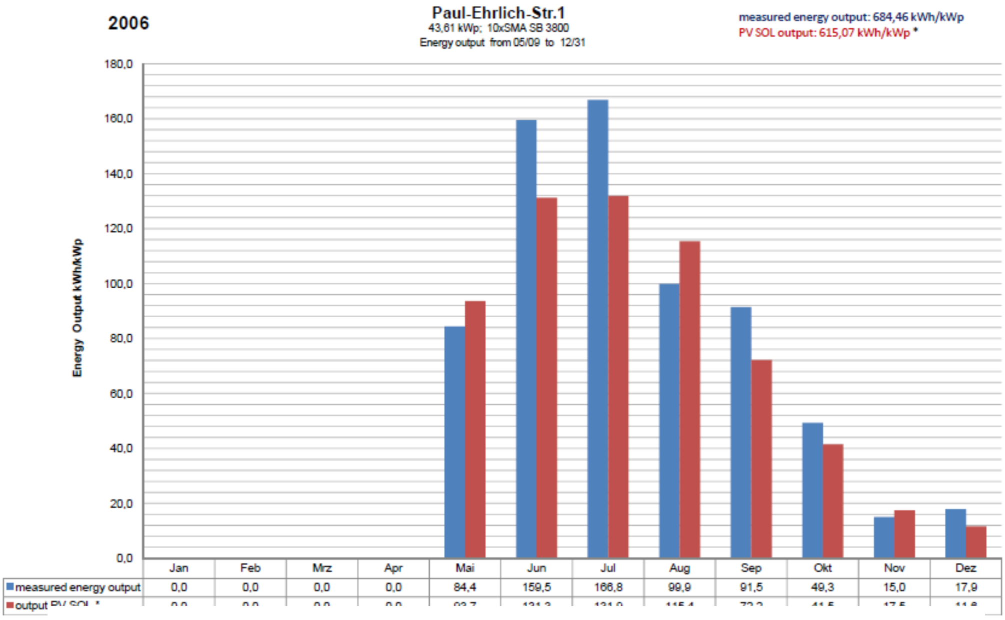
6.3 Actual Energy Yield

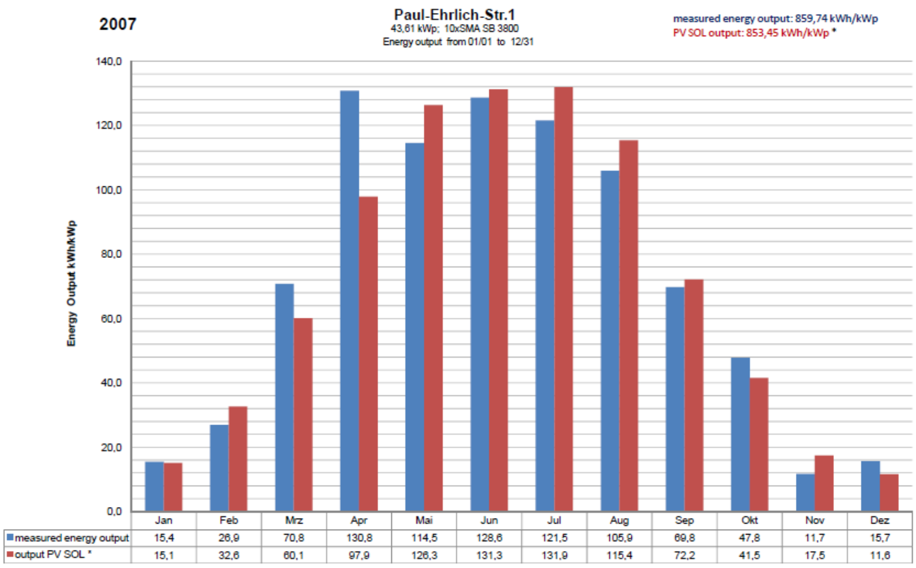
The actual energy yield measured, shows the accuracy of the forecasted specific annual energy yield, on which the investment decision was based.

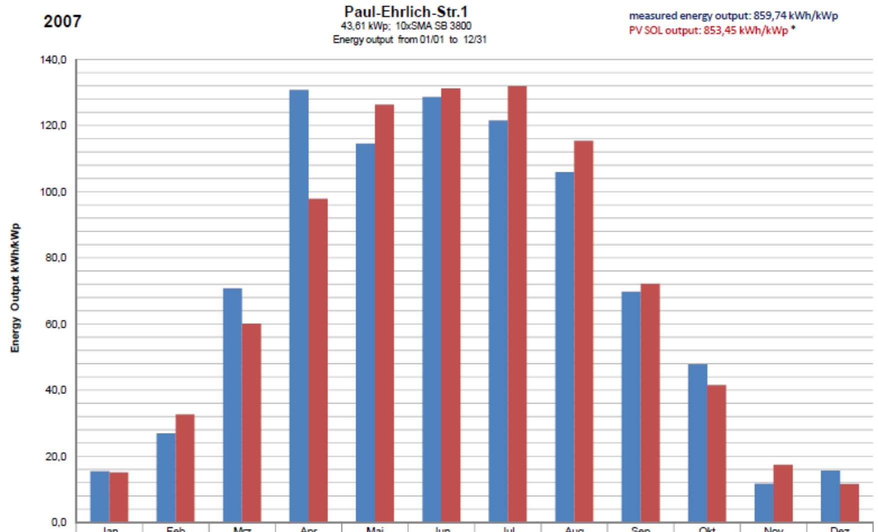
2006: forecasted 615 kWh/kWp – achieved 685 kWh/kWp

2007: forecasted 853 kWh/kWp – achieved 860 kWh/kWp

2008: forecasted 852 kWh/kWp – achieved 847 kWh/kWp







	Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
measured energy output	15,4	26,9	70,8	130,8	114,5	128,6	121,5	105,9	69,8	47,8	11,7	15,7
output PV SOL *	15,1	32,6	60,1	97,9	126,3	131,3	131,9	115,4	72,2	41,5	17,5	11,6

7. Conclusions

To achieve the objectives of the Kyoto Protocol, low energy building concepts need to integrate photovoltaic systems for clean power generation.

To make low-load bearing roofs of large industrial, commercial and institutional buildings available for photovoltaic installations and thereby increase the area available for renewable energy production, Solar Integrated developed the SolarRoof Membrane, which is lightweight, easy to install and durable.

Comparisons of various technologies as well as forecasted and achieved energy yields of individual installations confirm the excellent energy yield that can be achieved with this technology on the mentioned roof types with roof integrated – turning unused (roof) space into energy generating assets.

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Optimised low energy building concepts

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Abstract

The lifetime optimised planning and design concept is a repeatable and documented way of design, which can result in individual buildings or infrastructures with an optimised lifetime quality**.** Lifetime quality is the capability of a building to fulfil the requirements of the users, owners and society during entire design period of the building**.**

The lifetime building concept can be used in strategic development and product development as well as in the planning and design of individual objects of buildings and civil infrastructures.

This paper includes a description of the application of the lifetime design concept into development and design of optimised low energy building concepts. It includes generic definitions of requirements, as well as a specific description of the planning and design process, methodology and methods. Also a case example of application in the development of a building concept is described.

Keywords: Buildings, energy efficiency, lifetime quality, multiple requirements, optimisation

1. Generic lifetime quality

The method of the optimised design of the energy efficiency follows the generic integrated life cycle design for lifetime quality, although the focus lies in the energy efficiency [1, 2, and 3]. This is important, because the energy efficient buildings have to fulfill all generic requirements although the focus lies in the energy efficiency. A generic classification of the requirements of the lifetime quality is presented in table 1 [1, 2, 5, 6, and 7].

The terms and definitions of the Lifetime Engineering are presented in the reference publication [15].

Table 1. *Generic classified requirements of structures and buildings [1, 2, 5, 6, and 7].*

1. Human requirements • functionality in use • safety • health • comfort	2. Economic requirements • investment economy • construction economy • lifetime economy in: o operation o maintenance o repair o rehabilitation o renewal o demolition o recovery and reuse o recycling of materials o disposal
3. Cultural requirements • building traditions • life style • business culture • aesthetics • architectural styles and trends • imago	4. Ecological requirements • raw materials economy • energy economy • environmental burdens economy • waste economy • biodiversity and geodiversity

2. Generic integrated and optimising life cycle design

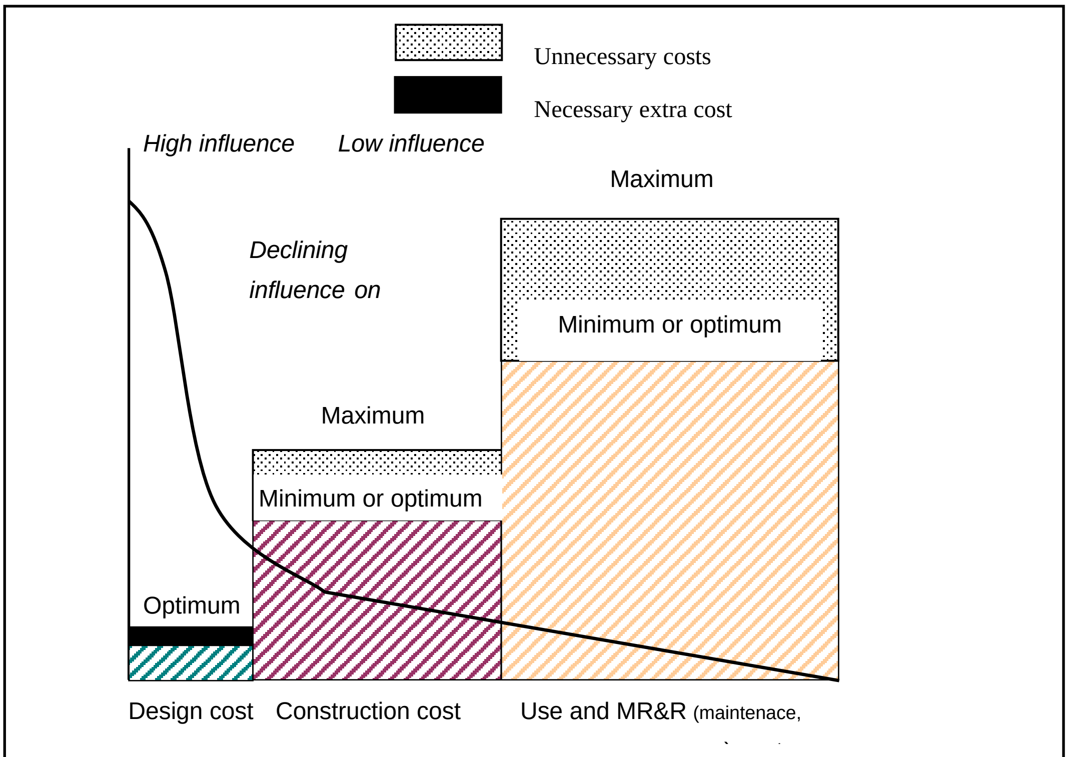
2.1 Principles

The generic integrated life cycle design process includes the following main phases of the design process: Investment planning, analysis of the actual requirements, interpretation of the requirements into technical performance specifications of structures, creation of alternative structural solutions, life cycle analysis and preliminary optimisation of the alternatives, selection of the optimal solution between the alternatives and finally the detailed design of the selected concept alternative [1, 2, 3].

The conceptual, creative design phase is very decisive in order to utilise the potential benefits of integrated life cycle design process effectively. The modular systematic helps the rational design, because the building typically owns different parts, here called modules, with different requirements e. g. regarding to energy efficiency, durability and service [1, 2, 6, 11, 12, 13 and 14].

The potential for optimising the lifetime quality, and the costs as a component of this quality, is highest at the first phases of investment planning and building project planning, and decreases gradually until the construction phase, where most components of the lifetime quality are already fixed. Another important phase follows in optimising maintenance, repair and rehabilitation (MR&R), where many important factors of operation and maintenance costs will be gradually optimised and fixed (figure 1).

The two main phases of optimising economic design can be called “Value Management” and “Cost Management”, which include different variables and information structures, as presented in figure 2. The first part of the design, which is performance oriented, will be made by a team of the architect and technical designers (structural and building service engineers), which work in close co-operation between each others as well as with the client and users. The second part, which is a concretising phase, is made in a close team of technical designers and manufacturers. The concretising phase is often connected to specific building concepts of contractors and their suppliers. In this way the current problem of diversified design and manufacturing processes can be avoided.



Modified from:John Kelly and Steven Male, Value Management in Design and Construction. E&FN SPON London. 1993.

Figure 1. *A small increase in planning and design costs can cause a considerable decrease of the lifetime costs [17].*

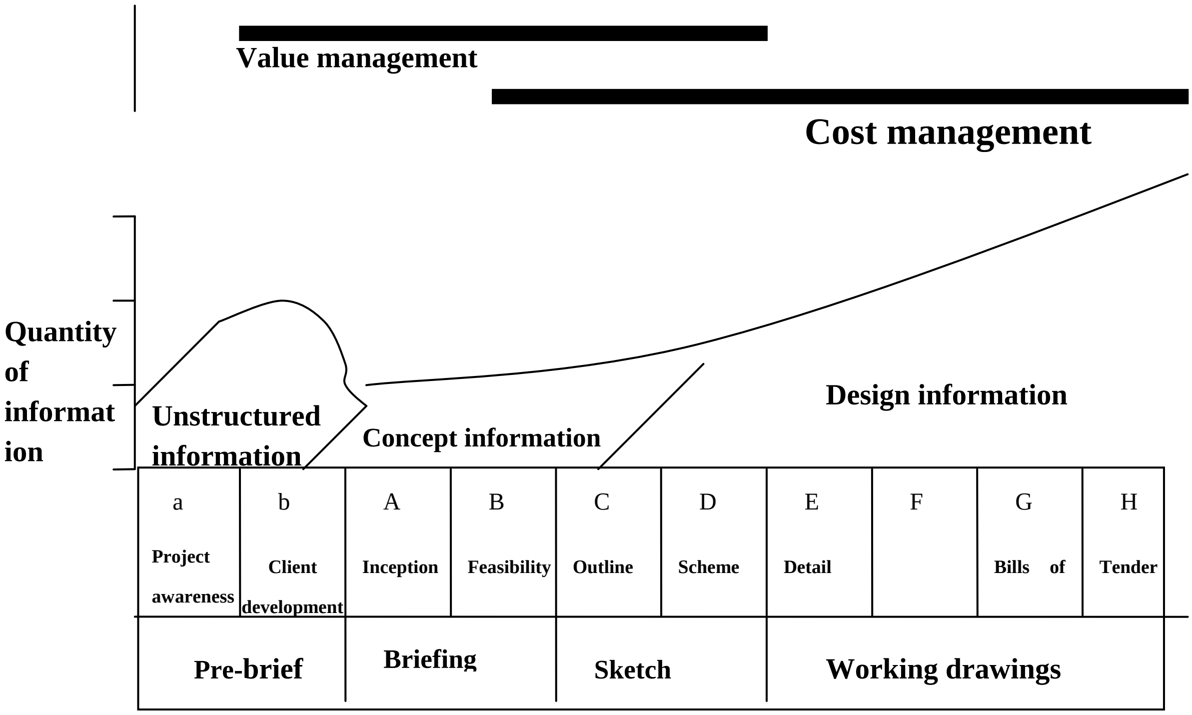


Figure 2. *Characteristics of the optimisation and decision making in different phases of the planning and design process [17].*

2.2 Methods

The following optimising principles can be applied at the optimising design for energy efficiency:

1. Life cycle costing (lifetime monetary economy)
2. Life cycle ecology (lifetime economy of the nature)
3. Multiple Criteria Decision Making:
   a. Analytic Hierarchy Process or
   b. Simplified Multiple Criteria method
   c. Quality Function Deployment (QFD) method

Life cycle costing method is standardised for example in the standards: ISO15686-Part 5 (Life Cycle Costs) and ASTM E 917-94. Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems.

Assessment of environmental impacts is based on the ISO-standards 14040 - 14043.

Multiple Criteria Decision Making (also called “Multi Attribute Decision Analysis) has been standardised in the USA standard: “American Society for Testing and Materials

(1995) Standard Practice for Applying the Analytic Hierarchy Process to Multi Attribute Decision Analysis of Investments Related to Buildings and Building Systems. ASTM Designation E 1765-95".

Quality Function Deployment (QFD) method is related to methods of linear programming which have been developed in 1950's and were widely used in 1960`s in product development of industry. In current formulation QFD was developed in Japan and it was first used in 1972 by Kobe Shipyard of Mitsubishi heavy industries in 1972 (Zairi 1995).

2.3 Methodology

The optimising selection between building concepts, design alternatives, systems, modules and components is carried out in different hierarchical levels at different phases of the project planning and building design (Table 2.).

Table 2. *Optimising procedures at different phases of the building project.*

Phase of the design process	Selection action
Pre-brief, Briefing	Select the building concept and its energy efficiency level.
Sketch planning, *phase 1*	Define the alternatives in: • the general architecture • technical specifications of the building envelop structures and key components and • technical specifications of the building service system.
Sketch planning, *phase 2*	Rank and decide between the alternatives of • the architecture • envelop structures and • building service system, in some parts interactively with energy delivery
	Select the key products (modules and components) of the building envelop and building service system
Detailed design and working drawings	Select all other components and materials of the building
Sketch planning, *phase 2*	Select the energy delivery and deliverers
Detailed design and working drawings	Document the user`s guidebook

2.4 Optimising design procedure at the building concept level

The optimisation procedure is based on creation of alternative design solutions and products, and on selection of the optimal solution among these in relation to selected dictating components of lifetime quality. The alternatives can be compared and ranked applying some of the methods listed above (Life Cycle Economy, Life Cycle Ecology, Multiple Attribute Decision Aid (MADA) or Quality Function Deployment (QFD).

In the planning and design process the generic requirements have to be modelled with technical and economic numerical parameters into quantitative models and procedures, and with semi-numerical or non-numerical ranking lists, classifications and descriptions into qualitative procedures [1, 2, and 6].

The selective optimising procedure of the optimal energy efficiency of a building concept is as follows:

1. Choose the practical alternative levels of the space heating energy need. Recommended upper limits of the space heating energy consumption at these levels are in Finland the following:
    - Finnish Standard House 2010 (need of space heating energy in Central Finland 90 kWh/(m^2,a)
    - Low Energy House (need of space heating energy in Central Finland 50 kWh/(m^2,a)
    - Finnish Passive House (need of space heating energy in Central Finland 25 kWh/(m^2,a)
2. Choose the approximate technical specifications of the envelop structures and buildings service systems:
    - an example of these specifications is in Table 3.
3. Calculate more exact values of the space heating energy need of each building concept alternative.
4. Change the technical specifications to correspond the calculated more exact values.
5. Select three suited alternatives (e. g. prefabricated houses, building concepts, or separate structural envelop systems and building service systems) for further comparisons
6. Seek after the product information of the alternative products, including:
    - energy technical service specifications, expected service life and ecological properties
    - price at the site delivery
    - expected assembly cost, if not included in the delivery
    - annual cost of technical maintenance and operation
    - need of repair during the design time period of 50 years
7. Calculate the differential life cycle costs of the alternatives, alternative 1 (usually the normative building) being the reference, at different time points, e. g.
    - at the end of the construction phase
    - for example at the age of 5 y, 10 y, 15 y, 30 y and 50 y after completion of the building
8. Evaluate the differential market value (sale value) of the alternatives
    - usually as a constant percentage of the original construction cost or of the sale value of the new building

9. Make the sensitivity analysis of life cycle cost in relation to a couple of key factors (e. g. interest rate and development of the energy price)
10. Rank the alternatives in relation to life cycle costs at different time points.
11. Select the best alternative for detailed design.
12. Move to detailed design of the architecture, structures and building service system.

The resulting definition of a building concept includes:

- systematised definitions of performance properties, classified hierarchically on the levels
    - of buildings and corresponding specifications of building systems,
    - of modules and components
- technical specifications, based on the performance properties:
    - of buildings and corresponding specifications of structural and building service systems,
    - of modules and components
- design rules for architectural, structural and building service design of the building, including process descriptions and
- examples of application

Table 3. *Approximate technical specifications of the building envelop structures and building service systems at different energy efficiency levels of the multistory apartment building [16].*

Technical factor	Finnish normative building code 2010	Low Energy House (space heating energy need 50 kWh/(m^2,a)	Passive house (space heating energy need 25 kWh/(m^2,a)
U-values, W/m^2K			
Bottom floor against the earth	0,16	0,10	0,10
Bearing and ventilated bottom floor	0,17	0,09	0,10
Bearing bottom floor against open air	0,09	0,08	0,08
External wall	0,17	0,14	0,12
Roof	0,09	0,09	0,08
Windows	1,0	0,9	0,8
Doors	1,0	0,6	0,6
Air leakage n50, 1/h	<2,0	<0,8	< 0,6

Annual efficiency of the heat recovery %	> 45	> 65	> 75
Specific electrical power need of the ventilation, kW/m^3/s	< 2,5	< 2,0	< 1,5

2.5 Energy distribution system and energy delivery

In comparison to the normative buildings, there are increased number of possible energy sources and deliverers in the case of low energy buildings, and especially in the case of passive buildings. This is the case, because the low amount of the energy need allows higher energy price. Deciding in this case is the original investment to the energy delivery. Examples of the suited energy sources for normative buildings, low energy buildings and passive buildings in Finnish conditions are presented in Table 4. The energy modes and suppliers can be selected with the generic procedure of selective optimising between the suited alternatives.

Table 4. *A generic example on the suited energy sources for normative buildings, low energy houses and passive houses in Finnish condition.*

Energy source	Economic and technical suitability in		
	Finnish Standard House 2010 N-90	Finnish Low Energy House M 26-50	Finnish Passive House P 15-25
District heating	Well suited	Possible	Generally not competitive
Electric Network	Generally not competitive	Possible	Well suited
Heat pump, driven with network electricity	Well suited	Well suited	Possible
Heat pump, driven with on-site electricity production	Possible	Possible	Possible
Wind energy	Well suited	Possible	Generally not competitive
Bio energy	Well suited	Possible	Generally not competitive
Combined sources of renewable energy: • wood fireplace • heat pump • solar energy collector • electric solar cells • wind energy	Suited as a specific combination	Suited as a specific combination	Suited as a specific combination

3. Example: Building concept “Inducon”

3.1 Concept alternatives

As a case is presented the design, economic and ecological optimisation and multiple attribute decision-making of an experimental building in Helsinki. The focus is on the energy efficiency. This optimisation has resulted the ranking of lifetime economy as a function of energy economy. Also the ecologic efficiency has been ranked. The alternative building concepts were the following [11, 16]:

1. Finnish Passive House (annual consumption of space heating energy = 25 kWh/living area [m^2])
2. Low energy house (annual consumption of space heating energy = 75 kWh/living area [m^2])
3. Standard house, Finnish energy standard 2003 (annual consumption of space heating energy = 100 kWh/living area [m^2])
4. Standard house, Finnish energy standard 2000 (annual consumption of space heating energy = 150 kWh/living area [m^2])

The objective of this research work has been to respond the challenges described above with creating alternative **building concepts**, which could allow production of individually designed apartment and office buildings, including methodology and methods to **optimise the building concepts and individual buildings** in relation to the **lifetime quality** [11].

3.2 Comparison of the lifetime economy

The calculation time periods were as follows:

- 10 years, typically the period of the first ownership.
- 25 years, typically the period without big renovations and a typical time of the investment loan.
- 50 years, the design time period.
- 100 years, prolonged design time period for economic and ecologic calculations.

The result of the lifetime cost calculations calculation of the “Inducon” test building are presented in Table 5. The costs are calculated as €/m^2 (living area) in the calculation time period of 50. Real interest rate is 2 %. These results are presented also graphically in figure 3, where also the cash flow during the calculation periods can be seen.

Table 5. *The construction costs, current values of the costs under the design time period of 50 years of Standard House 2003:n, Low Energy House and Finnish Passive House, as differential costs in comparison Standard House 2000.*

Cost category	Current value €/m^2 (*living area*)		
	Standard House 2003	Low Energy House	Finnish Passive House
Building envelop cost	+14	+27	+40
Cost of building service system	+23	+23	+25
Repair and renewal	+29	+30	+30
Service and maintenance	+6	+4	+4
Heating energy of spaces	-55	-190	-250
Investment interest cost	+20	+23	+28
Temporary accommodation during major repair works of the heating system		-7	-7
Total sum	+37	-90	-130

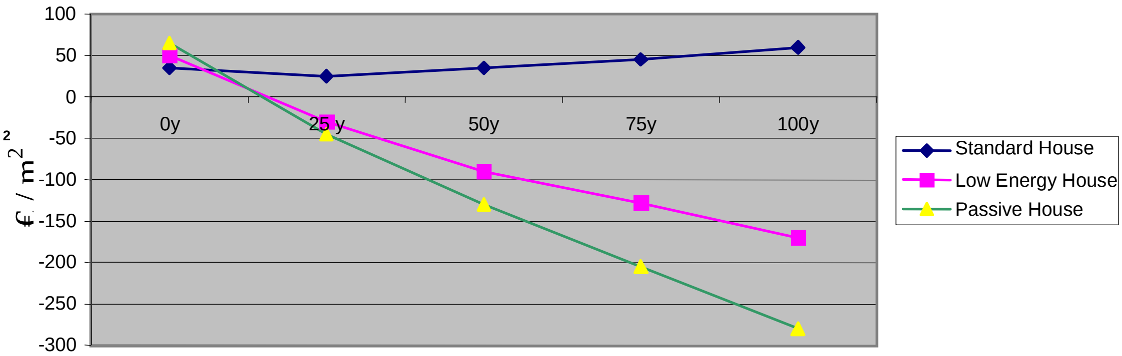


Figure 3. *Graphic illustration of the differential cash flow of Standard House 2003, Low Energy House and Finnish Passive House, in comparison Standard House 2000.*

The payback times of the differential investments of the alternatives can be seen in figure 3, and they are:

- unlimited (no payback) in case of the Standard House 2003
- 13 years in case of Low Energy House and
- 13 years in case of Passive House

3.3 Ecological comparison

The key factors of the ecology are the annual production of greenhouse gases (CO_{2ekv}) and of acid gases (SO_{2ekv}). The CO_{2ekv} represents global impact and the SO_{2ekv} local impact. Both of these burdens are also strongly related to the consumption of the non-renewal fossil primary energy. The ecologic comparison was made for the total heat energy need. This means that both the space heating energy, the heating energy for warm water supply and the electric energy were taken into account.

In this case the heating energy is delivered by the district heating plant of Helsinki city. The primary energy is consisting of the combination of coal and gas. Because the district heating plant of Helsinki city produces both heat and electricity, also the burdens of the electric energy where calculated for the example building.

The results of these calculations are presented in table 6.

Table 6. *Annual primary environmental burdens: CO_{2ekv} (kg/a) and SO_{2ekv} (kg/a) of the alternative building concepts, calculated for the total need of heat energy.*

	Standard house 2000	Standard building 2003	Low Energy House	Passive House
Need of heat energy MJ/a	3,10	2,29	1,54	1,14
CO_2 ekv kg/a	21 400	16 100	10 500	7 900
SO_2 ekv kg/a	350	253	170	135
Need of electric energy MJ/a	0,77	0,86	0,82	0,80
CO_2 ekv kg/a	2 350	2 640	2 515	2 465
SO_2 ekv kg/a	90	101	96	94
Energy, totally				
MJ/v	3,87	3,15	2,36	1,94
CO_2 ekv kg/v	23 750	18 740	13 015	10 365
SO_2 ekv kg/v	440	354	266	229

Based on the results (table 6) was calculated a numerical value of so called Relative Eco- Efficiency for each case I as a ratio [18]:

$$REE\ (I) = BP_{ref.} / BP_I$$

where

REE is the relative ecoefficiency

I the alternative building

ref. the reference building

Applying this method the following numerical values or stated:

- Standard house 2003: REE (ref.) = 1
- Low Energy House: REE(1) = 1,3
- Finnish Passive House REE(2) = 2,0.

The number of the relative ecoefficiency thus increases with increasing efficiency. These numerical values were used in the simplified multi attribute decision making for ranking the alternatives in relation to lifetime quality.

3.4 Multi Criteria Decision Making

The simplified multi criteria decision making method was used, applying the following five criteria:

- Lifetime costs: separated construction costs, maintenance costs and energy costs
- Healthy, Safety, Comfort
- Lifetime usability and changeability
- Lifetime ecology
- Cultural value

The cost level of materials, construction and energy (district heat and electricity) were the levels in the year 2002. Also the differences of the future value were evaluated at each time of calculation, modified into current value. All comparisons were made as differences between each alternative and the reference building (standard house 2000).

An additional boundary value was the limit of the construction cost, which was not allowed to be higher than 10 % in comparison to the reference building (Standard House 2000).

The criteria and weights the central lifetime quality factors were defined by owners as presented in table 7.

Table 7. *The weights of the lifetime quality factors.*

Factor	Defined weight or limit value	Ranking of the cases			
		Standard house 2000	Standard house 2003	Low Energy House	Finnish Passive House
Lifetime economy	Lifetime cost in 15 years and 50 years	3	4	2	1
Healthy, Safety, Comfort	10	4	3	2	1
Lifetime usability and changeability	10	4	3	2	1
Lifetime ecology	8	4	3	2	1
Cultural value	8	4	3	2	1
Total weighted ranking	-	4	3	2	1

3.5 Sensitivity analysis

Sensitivity analysis was carried out in relation to the real interest rate, energy price with the alternative values of these parameters (table 8). Results of this analysis as the payback times are listed in table 9.

Table 8. *Alternative values of parameters in sensitivity analysis.*

Parameter	Basic value in rating	Alternative value in sensitivity analysis
1. Real interest rate (= nominal interest – inflation)	2 %	4 % and 6 %
2. Energy price	The price of Helsinki energy in the begin of 2002	50 % higher price than in 2002

Table 9. *Results of the sensitivity analysis as a calculated payback time of additional investment for construction as a difference to standard house 2000.*

Alternative	Payback time of additional investment for construction as a difference to standard house 2000, years				
	Real interest rate			Energy price, real interest rate being 2 %	
	2 %	4 %	6 %	The price of the year 2002	50 % higher than in 2002
Standard house 2003	unlimited	unlimited	unlimited	unlimited	100
Low Energy House	13	15	19	13	10
Finnish Passive House	13	20	28	13	8

The following conclusions can be drawn from the sensitivity analysis:

1. The Standard House 2003 is always less economic than the Standard House 2000. This shows that minor changes in the energy efficiency always are uneconomic.
2. The ranking is in most cases: No 1: Finnish Passive House, No2: Low Energy House, Standard House 2003.
3. Finnish Passive House is somehow sensitive to the change of real interest rate with the energy price level of the year 2002. This has caused a change of ranking between Low Energy House and Passive House in cases of real interest rate of 4 % and 6 %.
4. The payback time on the Finnish Passive House diminish quite rapidly with increasing energy price.
5. The ranking between the alternatives and the decision for selecting the alternative energy efficiency level are quite stable in relation to the real interest rate and energy price, but the differences between the alternative increase with increasing energy price, and the raking between Low Energy House and Passive House changes with increased real interest rate.

4. Conclusions

The optimised building concept methodology is an effective way during development of specific building concepts. In this methodology can be combined generic lifetime quality and specific focusing of the target for energy efficiency. This type of the selective optimising procedure is especially suited for development of prefabricated building concepts, for generic bases of the building concept of a contracting company and for building concepts of owner and client organisations.

This methodology can be applied also in a simplified form in the design of individual buildings and even in the design and choice of structural or building service systems, as well as in the choice of suited energy delivery sources of building areas or individual buildings.

The results of the case study and some other corresponding comparisons indicate that the current need of space heating energy of the normative buildings is far above the economic lifetime optimum. This means that there is an economic potential for drastic change of requirements on energy efficiency of buildings. Ecologically this change is even more motivated. The increased market value and sale value of the Low Energy House and Passive House alone may probably cover already alone the minor differences of the construction costs, which typically are currently in Finland respectively 2-3 and 4-6 %.

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