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EC 5th Framework

PERFORMANCE BASED BUILDING THEMATIC NETWORK 2001-2005

DECISION SUPPORT TOOLKIT

PeBBu Generic Task 3 Final Report

Performance Based Building Thematic Network
Funded by EU 5th Framework Research Programme
Managed by CIBdf

Decision Support Toolkit

PeBBu GENERIC TASK 3

FINAL REPORT

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October 2005

This work was performed as part of the tasks for the EU-funded Performance Based Building Network.

Performance Based Building Network (PeBBu) is a thematic network funded under the European Commission's (EU) 5th framework – Competitive and Sustainable Growth and has been operational from October 2001 till September 2005. This project has been managed by CIBdf, The Netherlands. The PeBBu Network has been facilitating in enhancing the existing performance based building research and activities by networking with the main European stakeholders and other international stakeholders. The network has also been producing synergistic results for dissemination and adaptation of performance based building and construction. More than 70 organisations worldwide have been participating in the PeBBu Network.

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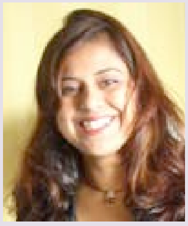

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FOREWORD

Decision Support Tools for Performance Based Building is an additional task that was started at PeBBu Mid Term based on recommendations of its Scientific Domains and conclusions of the project outcome at that stage. The task consisted of selecting seven promising decision support tools, testing their applicability in Performance Based Building and drawing recommendations based on the experiences. At present, many decision support tools exist already, even though they are not commonly used. In the future, it is very important to look at their interoperability in order to form an integrated platform providing a set of tools that can be used in different occasions by different users depending their needs in that phase of the process.

I want to express my special thanks to Janne Porkka from VTT, the 'machinist' of our team, who was also the main author of the large documentation forming the basis for this report. We are grateful for our collaborators at Reading Dr. Salam Al-Bizri and Professor Colin Gray. Special thanks to Marcel Loomans at TNO, who kindly organised the first tool testing occasion for this task. He also contributed to the report in a value adding way compling information on one 'additional tool' (iBUILD) identified at that stage. Compliments to the Dutch PBB pioneers George Ang and Dik Spekkink for their encouraging support in the first trial in Delft. Thanks to the CIB secretariat and PeBBu Domain leaders that gave us the opportunity of testing our tools in their sessions in the second tool testing occasion in Porto. Thanks also to the PeBBu community for their support and finally thanks to all those who have made it possible that we have such PBB DSTs available: EcoProP (Jarkko Leinonen & the Finnish team), QFD (the Reading team + Jarkko Leinonen & Ilkka Heinonen at VTT), MCDM (HUT Decisionarium in Finland), DSM (MIT in the US & the VTT team lead by PhD. Kalle Kähkönen etc.), POE (Preiser at al.) and iBUILD (the Dutch team).

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EXECUTIVE SUMMARY

This report describes seven value management, value engineering and process management tools that can be used in different phases (briefing, design, delivery, operation) of the performance based building process. These tools are

- Check Lists
- Requirements Management (EcoProP)
- Quality Function Deployment (QFD)
- Multi Criteria Decision Making (Hipre)
- Design Structure Matrix (DSM)
- iBuild
- Post Occupancy Evaluation (POE).

These tools were tested in two occasions together with the PeBBu community in its scientific domains. Experiences from those tool tests are described and recommendations drawn based on them. A wide list of references is collected at the end of the report.

The main conclusions as recommendations for the future work are summarised below

- a common international framework and universal performance classification
- an integrated platform with interoperable applications
- a performance based building roadmap
- value adding whole life services
- information dissemination, regulations and education.

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Decision Support Tools for PBB

CHAPTER 1

1 Decision Support Tools for PBB

This report gives an overview of selected decision support tools suitable for performance based building. Their applicability and deficiencies are presented and their interoperability is discussed. The most promising tools are presented more in detail. The approach covers both the life cycle of the building and the integration platform for feasible tools.

The selection of prominent decision support tools was guided by the following criteria
1. The whole life cycle of the product in question must to be covered
2. The tools need to support performance based building and different PeBBu domains.

The applicability of different tools in specific phases of the life cycle process (briefing, design, delivery, operation) is also highlighted. Tools are considered by numbers from 1-3 indicating their applicability priorities. The numbering is clarified with colours.

The tools are classified in the following (partly overlapping) categories; value management (POE, CL, RM, QFD), value engineering (QFD, MCDM) and process management (DSM, iBUILD).

Value Management, Value Engineering and Process Management

Value management and value engineering form structured framework for decision making. This paper describes them as umbrellas containing individual decision support tools supporting performance based building. Process management is proposed here as the third category providing means to re-engineer processed meeting better the needs of performance based building.

According to Green (1992) the sequence in value management builds up from making problem analysis, comprising alternative solutions and selecting the best solution. Value engineering is a continuum to value management and is guided by the project progress. Typically, value management workshops are held during the early phase of a building project (Green 1994). These take place normally in definitions of the concept and the feasibility. Since then value management evolves to value engineering. Value engineering workshops support design and detailed design.

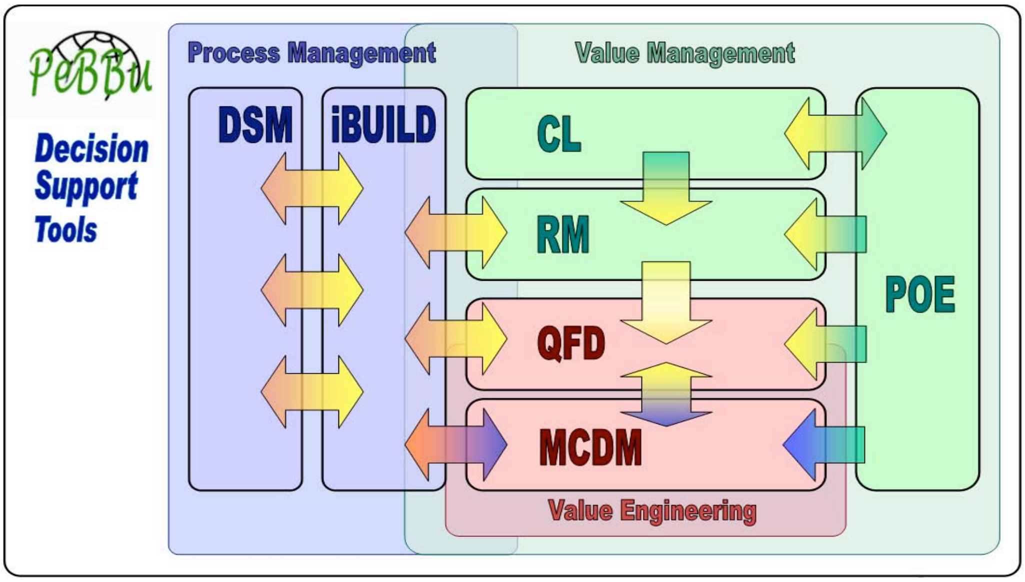

Figure 1: PeBBu decision support tools framework.

1.1 Check Lists

Long life cycle of the building, mainly the use and maintenance period, demands requirement management and effort targeted to early phase of a construction project. Therefore, many lists directing the classification of requirements have been developed during 20th century. In ancient history, same concepts have also been determined. Already 2000 years ago roman architect Marcus Vitruvius Pollio (1960) described in his Ten Books on Architecture the first classification. It contained the following three properties:

- Firmitas (*firmness, durability*)
- Utilitas (*performance, conformity*)
- Venustas (*aesthetics*).

Increasing number of building properties classifications have been published since 1940s. The first trial to establish a generally approved classification took place in Sweden. Swedish SfB system (Samarbeteskommittén för Byggnadsfrågor – Joint Working Committee for Building problems) was published in 1947-1949 and attained acceptance in local context. In the SfB system the functional elements defining the performance of the building described the final product. Therefore, this classification wasn't taken into consideration and focus was targeted to subsequent classifications.

This chapter gives a short overview on different performance classifications.

1.1.1 CIB Master Lists

First international effort for generically approved classification was based on the foundation of Swedish SfB system. Proposal of a CIB Master List, written by Ingvar Karlén, came out in 1959. CIB (International Council for Research and Innovation in Building and Construction) started the development of a classification named CIB Master List (CIB 2004).

Until now, four classifications have been published by CIB. First edition saw daylight in 1964 with a title of the properties of building materials and products (CIB 1964). After this the Master List has been updated in 1972 (CIB 1972), 1983 (CIB 1983) and 1993 (CIB 1993).

1.1.2 ISO 6241 Performance Standards for Buildings

The 1983 edition contained in addition to the earlier ones lists for Agents and User requirements that were later published as ISO 6241 (1984) Performance standards for buildings. The ISO standard includes tables for User requirements, Uses of buildings and spaces, Subsystems of the building fabric and Agents relevant to building performance.

User requirements are statements of need to be fulfilled. In the user requirements table, the unified list of items in performance classification is announced. This list can be considered as a preparation of performance standards.

USER REQUIREMENTS
1. Stability
2. Fire safety
3. Safety in use
4. Tightness
5. Hygrothermal
6. Air purity
7. Acoustical
8. Visual
9. Tactile
10. Dynamic
11. Requirements for the suitability of spaces for specific use
12. Durability
13. Economic

Figure 2: User requirements of ISO 6241 (ISO 6241 – 1984).

Another addition of ISO 6241 is the Agents list. These Agents are driving forces of building performance and describe five categories (ISO 6241 – 1984):

AGENTS	
1.	Mechanical agents (Gravitation, Forces and imposed or restrained deformations, Kinetic energy, and Vibrations and noises)
2.	Electro-magnetic agents (Radiation, Electricity, and Magnetism)
3.	Thermal agents
4.	Chemical agents (Water and solvents, Oxidizing agents, Reducing agents, Acids, Bases, Salts, and Chemically neutral)
5.	Biological agents (Vegetable, and Animal)

Figure 3: Agents of ISO 6241 (ISO 6241 – 1984).

Development of ISO 6241 standard is relevant for the whole performance approach. Generally, previously presented lists of User requirements and Agents have been widely adapted to foundations of further development efforts.

1.1.3 European Commission Construction Products Directive

In the year 1989 European Commission published Construction Products Directive (CPD) that determined six essential requirements. These requirements were taken into Annex I of the newest edition of CIB Master List in 1993 and replaced ISO 6241.

ESSENTIAL REQUIREMENTS
1. Mechanical resistance and stability
2. Safety in case of fire
3. Hygiene, health and the environment
4. Safety in use
5. Protection against noise
6. Energy economy and heat retention

Figure 4: Essential requirements in the Construction Products Directive (EC 1989).

Nevertheless, the Construction Products Directive is in more general level than the rest of CIB Master List in edition 1993. On the other hand it is obvious, that classifications for construction products and whole buildings are different.

1.1.4 CIB Master List 1993

As presented earlier, the CIB Master List has been during past years under development before it has detected the final path. In the 1993 version also the Construction Products Directive is included. Hence, many individuals have noticed the importance of ISO 6241 (1984).

The newest edition defines CIB Master List as an internationally agreed list of headings for arrangement and presentation of information used in design, construction, operation, maintenance and repair of buildings and building services, and in associated documents on the supply of construction products and services, their manufacturers and suppliers (CIB 1993).

CIB Master Lists are known widely. Despite their international status, salient position isn't obtained. However, they are broadly adapted to a common language and provide definitions for performance properties. Additionally CIB Master Lists are utilised as a development basis.

PERFORMANCE
1. Active: capacity, output, consumption
2. Structural, mechanical
3. Fire
4. Gaseous, liquid, solid
5. Biological
6. Thermal
7. Optical
8. Acoustic
9. Electric, magnetic, electro-magnetic radiation
10. Resistance to attack
11. Service life, durability, reliability

Figure 5: The performance section (chapter 4) of CIB Master List 1993 (CIB 1993).

1.1.5 Whole Building Functionality and Serviceability

American National Standards Institute (ASTM 2004) is a developer and publisher of technical information designed to promote understanding and advancement of technology and to ensure the quality of commodities and services, and the safety of products. Institutes primary mission is developing voluntary full-consensus on the issues referred to above (ASTM 2000).

Many associations and institutes are associates of ASTM. Accordingly, the work is carried out through subcommittees. These subcommittees have released individual standards congregated to a classification in ASTM Standards on Whole Building Functionality and Serviceability.

Individual standards were published in 1995. Since, those have been approved regularly. Classification is a combination of characteristics in functionality, which is a subset of performance, and serviceability. Serviceability includes also a process related attributes like property management. The ASTM structure differs greatly from CIB Master List.

User-friendliness is leading characteristic of ASTM standards. Technical definitions have been replaced with easy-to-understand terminology. According to authors, the structure doesn't include enough performance characteristics.

TOPICS OF THE SERVICEABILITY SCALES	
Occupants' group and individual effectiveness	
E 1660	Support for office work
E 1661	Meetings and group effectiveness
E 1662	Sound and visual environment
E 1663	Typical office information technology
E 1692	Change and churn by occupants
E 1664	Layout and building features
E 1693	Protection of occupant assets
E 1665	Facility protection
E 1666	Work outside normal hours or conditions
E 1667	Image to public and occupants
E 1668	Amenities to attract and retain staff
E 1694	Special facilities and technologies
E 1669	Location, access and wayfinding
The property and its management	
E 1700	Structure, envelope and grounds
E 1701	Manageability
E 1670	Management of operations and maintenance
E 1671	Cleanliness

Figure 6: ASTM Standards for whole building functionality and serviceability (ASTM 2000).

1.1.6 Green Building Challenge

Green Building Challenge (GBC 2004) is an international collaborative effort to develop a building environmental assessment tool for the potential energy and environmental performance of buildings and from which the participating countries get new ideas. Supporting project of the tool introduces improvements and test results every second year in a conference that promotes information exchange between research community and building practitioners.
First results of GBC framework were presented in GBC '98 Vancouver. Assessing building energy and environmental performance culminated in the Sustainable Building 2000 Conference held in Maastricht Netherlands. Name of GBC conference was changed to SB, substance remained same. After two years Oslo organised SB 2002 and next will take place in Tokyo 2005.

GBC process is managed by an international umbrella organisation iiSBE, which stands for the International Initiative for a Sustainable Built Environment (iiSBE 2004).

GREEN BUILDING CHALLENGE CLASSIFICATION	
R	**RESOURCE CONSUMPTION**
R1	Life-Cycle net primary energy use
R2	Use of land and change in quality of land
R3	Net consumption of potable water
R4	Re-use of existing structure or materials and/or recycling of materials off-site
R5	Amount and quality of off-site materials used
L	**LOADINGS**
L1	Emission of greenhouse gases
L2	Emission of ozone-depleting substances
L3	Emission of gases leading to acidification
L4	Emissions leading to formation of photo-oxidants
L5	Emissions with eutrophication potential
L6	Solid wastes
L7	Liquid Effluents
L8	Hazardous wastes
L9	Environmental impacts on site and adjacent properties
Q	**INDOOR ENVIRONMENTAL QUALITY**
Q1	Air Quality and Ventilation
Q2	Thermal Comfort
Q3	Daylighting and Illumination
Q4	Noise and Acoustics
Q5	Electro-Magnetic Pollution
S	**SERVICE QUALITY**
S1	Flexibility and adaptability
S2	Controllability of systems
S3	Maintenance of performance
S4	Privacy and access to sunlight and views
S5	Quality of amenities and site development
S6	Impact on quality of service of site and adjacent properties
E	**ECONOMICS**
E1	Economic Performance
M	**PRE-OPERATIONS MANAGEMENT**
M1	Construction Process Planning
M2	Performance Tuning
M3	Building Operations Planning
T	**COMMUTING TRANSPORT**
T1	Emission of greenhouse gases
T2	Emission of gases leading to acidification
T3	Emissions leading to formation of photo-oxidants

Figure 7: Green Building Challenge classification (GBTool 2002).

1.1.7 Leadership in Energy and Environmental Design

Besides GBC framework, in 2001 the participating committee in United States (called USGBC) started a GBC based development framework called LEED Green Building Rating System. Classification concentrates on sustainability issues.

Main principle in LEED is to provide a sustainability report for a building. A property gets certain project total points. Highest rating is Platinum, which is followed by Gold, Silver and Certified. Sustainability report includes sustainability scenarios, comparison summaries and reference material in appendices.
Work has been implemented in two sections

1. New construction and major renovations (LEED-NC)
2. Existing buildings and operations (LEED-EB).

LEED-NC, VERSION 2	
Sustainable Sites	**Materials & Resources**
1. Erosion & Sedimentation Control	1. Storage & Collection of Recyclables
2. Site Selection	2. Building Reuse
3. Urban Redevelopment	3. Construction Waste Management
4. Brownfield Redevelopment	4. Resource Reuse
5. Alternative Transportation	5. Recycled Content
6. Reduced Site Disturbance	6. Local/Regional Materials
7. Stormwater Management	7. Rapidly Renewable Materials
8. Heat Islands Reduction	8. Certified Wood
9. Light Pollution Reduction	**Indoor Environmental Quality**
Water Efficiency	1. Minimum IAQ Performance
1. Water Efficient Landscaping	2. Environmental Tobacco Smoke Control
2. Innovative Wastewater Technologies	3. Carbon Dioxide Monitoring
3. Water Use Reduction	4. Vebtilation Effectiveness
Energy & Atmosphere	5. Construction IAQ Management Plan
1. Fundamental Building Systems Commissioning	6. Low-Emitting Materials
2. Minimum Energy Performance	7. Indoor Chemical & Pollutant Source Control
3. CRC Reduction in HVAC&R Equipment	8. Controllability of Systems
4. Optimize Energy Performance	8. Thermal Comfort
5. Renewable Energy	8. Daylight & Views
6. Additional Commissioning	**Innovation & Design Process**
7. Ozone Depletion	1. Innovation in Design
8. Measurement & Verification	2. LEED Accredited Professional
9. Green Power	

Figure 8: LEED-NC Rating System Version 2 (LEED-NC 2003).

Green Building Rating System has been tested in pilot projects. The LEED Steering Committee approved the pilot drafts in 2002. Pilot projects have been running since and for example LEED-EB has over 90 case studies. Work is organized on a voluntary basis and pilot participants prepare and test approved standard (LEED 2004). Structure is currently under development.

GBC and LEED classifications have much strength, comprising environmental viewpoints to certain aspects of performance, services and economics. As described earlier, the nature of classification has exploited effectively. Sufficiency of performance indicators is a question mark in both classifications because focus has been directed to elsewhere.

1.1.8 VTT ProP® Performance Classification

An internal requirement classification development project started in 1997 at Technical Research Centre of Finland (VTT) aiming to define a classification for building performance indicators. Conceptually, performance requirements set by owners, users and society evolve in design process to technical solutions which cause certain life-cycle costs and environmental pressure.

Analysis of previous and currently used classifications formed the foundation. Baseline of the VTT ProP® classification was that performance, life-cycle costs and environmental pressure originate from construction and use. In early stages, structure expanded to contain also conformity, including issues of location, spatial systems and services. An overall, VTT ProP® is designed for buildings to consider performance and sustainability without forgetting whole built environment.

VTT ProP® classification manages well in describing various requirement types and adapts to changing conditions and context. One of the leading guidelines was avoiding conflicts. Structure minimises those vague situations when user has problems in detecting logical placement for a requirement. Similar context is placed under same heading to avoid misinterpretation.

VTT ProP® PERFORMANCE CLASSIFICATION
A CONFORMITY
A1 LOCATION
A1.1 Site characteristics
A1.2 Transportation
A1.3 Impact on surroundings
A2 SPATIAL SYSTEMS
A3 SERVICES
B PERFORMANCE
B1 INDOOR CONDITIONS
B1.1 Indoor climate
B1.2 Acoustics
B1.3 Illumination
B1.4 Vibration conditions
B2 SERVICE LIFE AND DETERIORATION RISK
B3 ADAPTABILITY
B4 SAFETY
B4.1 Structural safety
B4.2 Fire safety
B4.3 Safety in use
B4.4 Intrusion safety
B4.5 Natural Catastrophes
B5 COMFORT
B6 ACCESSIBILITY
B7 USABILITY
C COST AND ENVIRONMENTAL PROPERTIES
C1 LIFE CYCLE COSTS
C1.1 Investment costs
C1.2 Operation costs
C1.3 Maintenance costs
C1.4 Demolition and disposal costs
C2 ENVIRONMENTAL PRESSURE
C2.1 Biodiversity
C2.2 Resources
C2.3 Emissions

Figure 9: VTT ProP® performance classification (2004).

1.2 Systematic Requirements Management

Descriptions of technical solutions are currently guiding design phase and space layout is fixed too early in many cases. Architects first space layout proposal leads the design phase and alternative solutions mean too technical solutions whereas they should be inherited from activities taking place in the building. Described road opens out to a value lose to a user. During product life time the most important decisions take place in the definition phase. Practically, it can be argued that successful project definition phase leads more likely to satisfied customers. Present construction process is mainly production driven although buildings should be made for customers. Certain problems in client need capturing and defining property value have been detected (Huovila et al. 1998; Kumaraswamy 1997). Furthermore, it is obvious that turnover improves when customer expectations are fulfilled (Lindkvist 1996; Smith et al. 1998).

Nature of problems has remained same for many decades (Barrett 1996). Overalls, deficiencies are noticed but actions to fix them are lacking. Some evident problems existing (Ohrn 1998; Kähkönen 1999; Lahdenperä 1998; Huovila 1999; Koskela 2000) are

- the brief has unclear or conflicting objectives
- original requirements are not documented in the brief
- transformation lacks creativeness and flexibility
- contractor selection bases only on the price of the production capacity
- there is communication problems during the construction phase
- cutting corners causes deficiencies in defining essential requirements.

Problems defined above concern whole project scale. Deficiencies of briefing process must also be considered. Kamara et al. (1999) stated four of them as follows

- often no formal or structured procedure in the evaluation of the brief is applied
- horizontal stakeholder integration is inadequate (communication problem)
- lack of IT support causes problems when requirements are changed
- link between requirement management and decision making is missing.

Nowadays the decisions lean strongly to share of investment costs. This development is alarming; governments and authorities are guiding development towards sustainable construction. For example in Finland there is effort targeted to setting values regarding life time energy consumption already in design phase. In the future, there is a vision shared where contractors take responsibility over the building life time. Specialists expect that this trend will be forthcoming main steam.

Requirements management is targeted to increase products value. In facilities, this means that the building performs better in its desired use. Practically, building is designed to support tenants' core business. It's obvious that human and organisational questions need more attention than technical aspects with the analysis of client's needs (Lindkvist 1996). Open and transparent communication amongst the parties involved is emphasised.

As Leinonen et al. (2003) states that the major problems in the implementation of the performance approach and requirements management are

1. The client does not trust the construction companies to provide the quality that is expected unless technical solutions are described in detail
2. There are no tools in wide use that would support the implementation of the performance approach
3. There is not enough knowledge (or understanding) of the performance approach in the construction industry.

1.2.1 Theory

Following theory leans on summary represented by Leinonen at al. (2001). According to this, there are experiences attached. The requirements management process ensures that we know what the customer wants and that the solution efficiently meets these requirements. There is also other terms meaning the same procedure, like requirements engineering. Requirements management represents up-front work, for which benefit does not appear until later. The goal is to understand, model and analyse the needs of users and stakeholders' task for validating whether the vision is correct. The purpose is to establish a complete, consistent and unambiguous requirements specification. It is emphasised that requirements management process is a continuous and evolving procedure that follows the whole life time of the building. Capturing the user needs is critical for maximising the value of the end product. This is the ultimate target of requirements management. Since it is impossible to satisfy all the needs of relevant stakeholders the practical objective of requirements engineering is to merge various user requirements to a realistic but holistic solution. Effective decision support tools to facilitate this are needed.
The end product of the building construction, the building, should fulfil the needs of all stakeholders in a comprehensive manner. In order to attain this, the user requirements need to be captured. This is the first target of requirements management. Since it is impossible to satisfy all needs of all stakeholders for various reasons the second target of requirements engineering is putting the separate user requirements together. And the compliance of design with the requirements should be verified constantly during the project. When requirements of the various stakeholders contradict, it is difficult to judge whose need is more important than other's. It's suggested that the ranking of stakeholders' opinion is based on the power, interest and proximity of the stakeholder.

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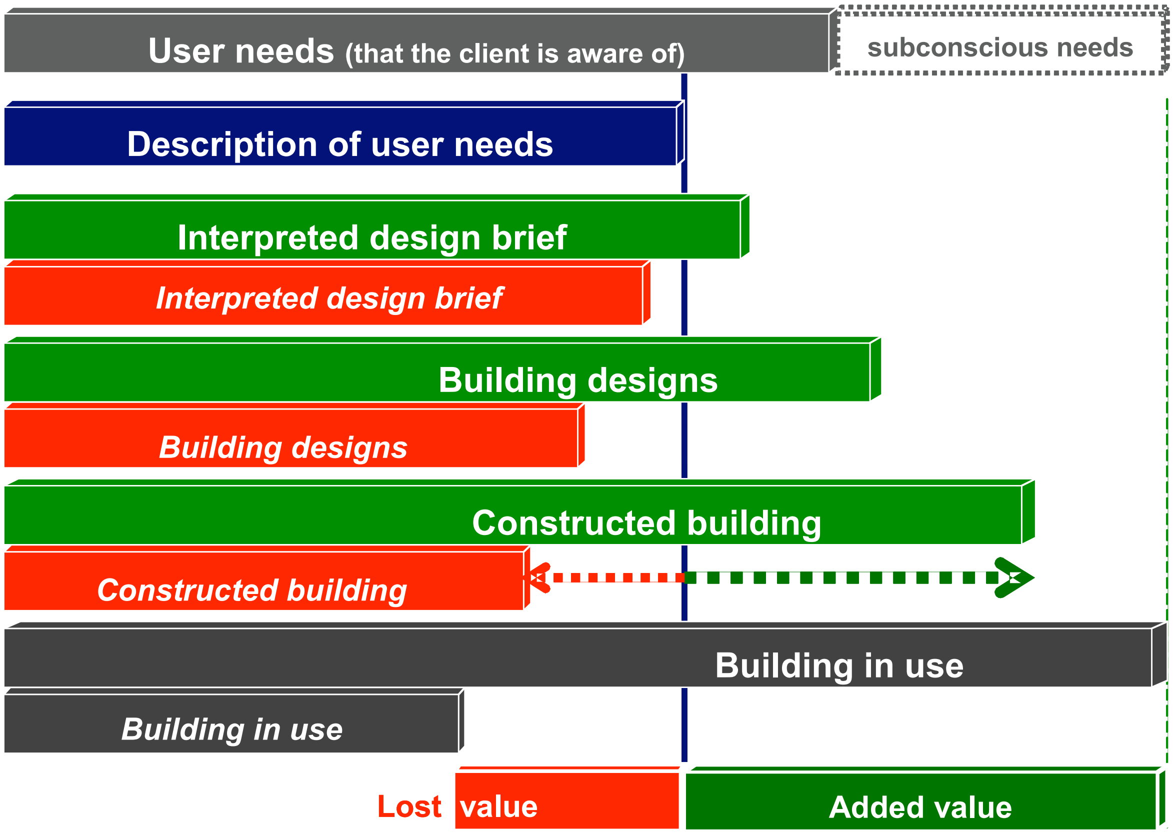


Figure 10: Purpose of requirements management, discontinuities in nowadays procedures (lost value).

General requirements management problems are: communication problems between developers and users, lacking of a systematic approach, need for domain knowledge, and changing management. Stakeholder often sees the requirements effort as a disturbance to their normal work. Part of the requirements are missed or lost at the briefing or during the design process. Maintenance requirements are missing in concept design phase. There are no effective means to integrate clients' requirements into the design process and ensure their following. Many key contributors are identified and included too late into the process.
To designer or engineer the performance based requirements give a possibility to fully exploit their knowledge accomplishing creative and flexible solutions. If performance based requirements belong to current practice the variety of procurement methods is larger. In that case, the contractors can improve design and gain benefits from following actions (Lahdenperä 1998).

Cole (1998) pointed out that many indirect benefits are consequence of the use of environmental assessment methods. He addressed that both communication and interaction between design team members improve. This development is a collaboration of various building industry sectors communicating and encouraging dialogue towards teamwork.

1.2.2 Process Steps

Steps of the requirements management process in performance based building are

1. Define and set requirements
2. Specify verification
3. Control change management.

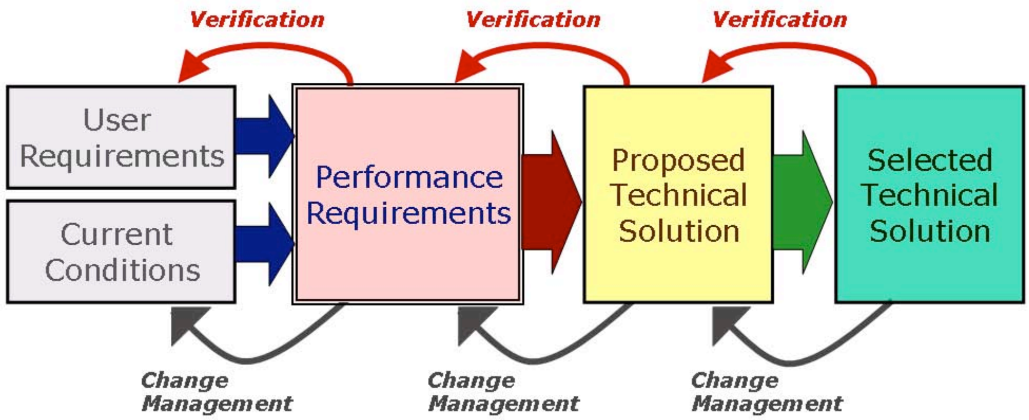


Figure 11: Requirements management process in performance based building.

First, the users are recognised. In this context a user means relevant project stakeholders, like occupants, owners and financiers of the building (CIB 1982). Besides user recognition, the activities taking place in the building need to be investigated. Use of building sets requirements which are often qualitative statements (Gross et al. 1986). Based on these user requirements and current conditions around (i.e. climate, infrastructure etc.) the quantitative performance requirements are set. A requirement is a statement that identifies capability, physical characteristics, or quality factor of pursued solution. According to Leinonen et al. 2001 (originally from many sources), good requirement is complete, unambiguous, consistent, feasible, neutral, traceable, necessary, correctly employed, concise, correct and verifiable.

Hierarchical approach to structure of requirements brings us closer to applying performance classifications. Different classifications are a solid basis to construct more comprehensive requirement definition sets. Requirement definition sets cover different objectives and situations.

Technical solutions proposed during the design phase are verified against the performance requirements. The most suitable technical solutions are selected. Verification methods have an important role in requirements management. In addition to verification during design phase it is important to verify that the desired performance is also reached during the operation (Sneck 1988). Authors have detected a common concern among practitioners against performance approach. Some have argued that it requires too much effort and time and finally doesn't generate requested information. This is acknowledged as a misunderstanding of objectives and failing the utilisation process.

During the project the emphasis changes from setting requirements to change management. Far too many practitioners have a false believe that the requirements remain same after setting them at the early phase. Promising results always require a continuous requirements management task and comprehensive efforts. Volume of required effort diminishes continuously when emphasis is targeted further to change management.

1.2.3 Tools: EcoProP software

Requirements management tools aim to provide applicable and updatable information for following project phases. It is a challenge to capture and maintain both expressed and unexpressed requirements of different stakeholders. One should not forget that along the process we must ensure that achieved results correspond to what was needed.

One of the drivers for the performance approach implementation in Finland has been EcoProP (EcoProP 2004). Tool has been developed in Finland but is previously gathering development efforts also in Australia. Software is an embodiment of systematic management of building project requirements. It helps to fulfil customer requirements and expectations by describing the properties of the final product using a hierarchical approach. It merges a requirement definition set database to simple and well structured user interface. Software is originally designed to construction and building domain but it is also applicable to wider and different purposes by adding new requirement definition sets.

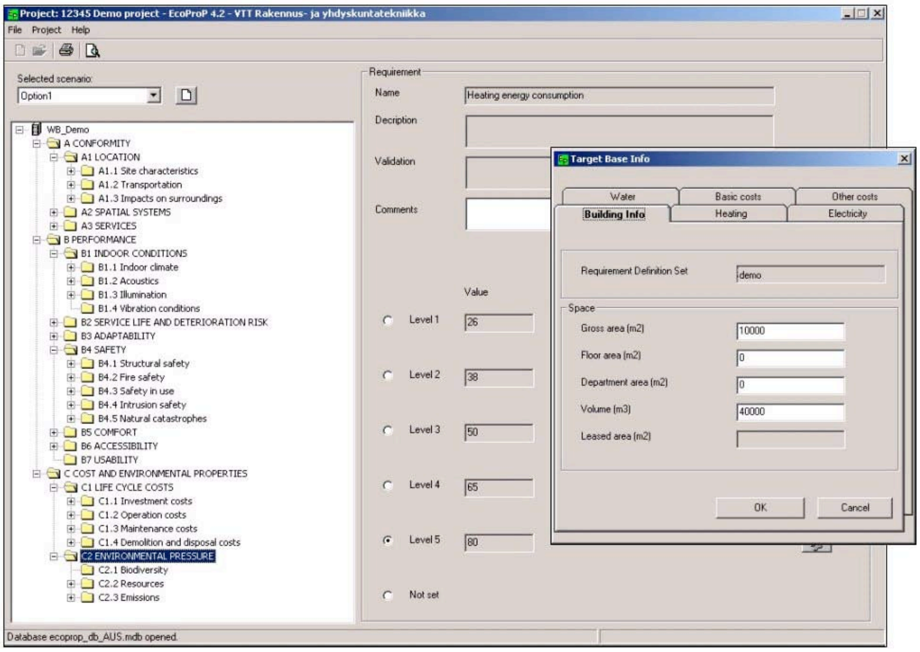


Figure 12: EcoProP software (EcoProP 2004).

The hierarchy has two levels. First, a classification is defined. After the classification definition, a requirement definition set is structured under approved classification. When requirement definition set is active a new project can be created. Projects contain also verification method and user defined relevant information about the requirements. In project level the requirements have different preset performance 'levels' for evaluation. It is possible to specify different scenarios under same project. This is exploitable when there is alternative ways to state performance requirements (i.e. in office building there can be room layout or an open office). The database includes classifications, requirement definition sets and projects. Software generates a life cycle cost calculation, environmental pressure calculation and earlier defined relevant reports for the stakeholder. In brief the needs of the society and stakeholders lead to alternative with certain investment costs. During the period of use and maintenance the largest share of life cycle costs become true and building performs certain environmental pressure.
Classifications and requirement definition sets are flexible. In Finland, the undertaking projects have exploited mostly VTT ProP® classification, which is a performance based classification for properties.

Main advantage of the software is providing a report to design brief appendix that includes sufficient amount of required performance information. The technical solutions can then be designed based on the specified performance requirements. User can define numerous reports with desirable content. Reports can be prepared for example from the perspective of thematic groups or different stakeholders. EcoProP can also estimate life-cycle costs associated with different scenarios during the construction and the use and maintenance period. Environmental pressure (Environmental indicators) is also calculated based on the energy usage during the operation time.

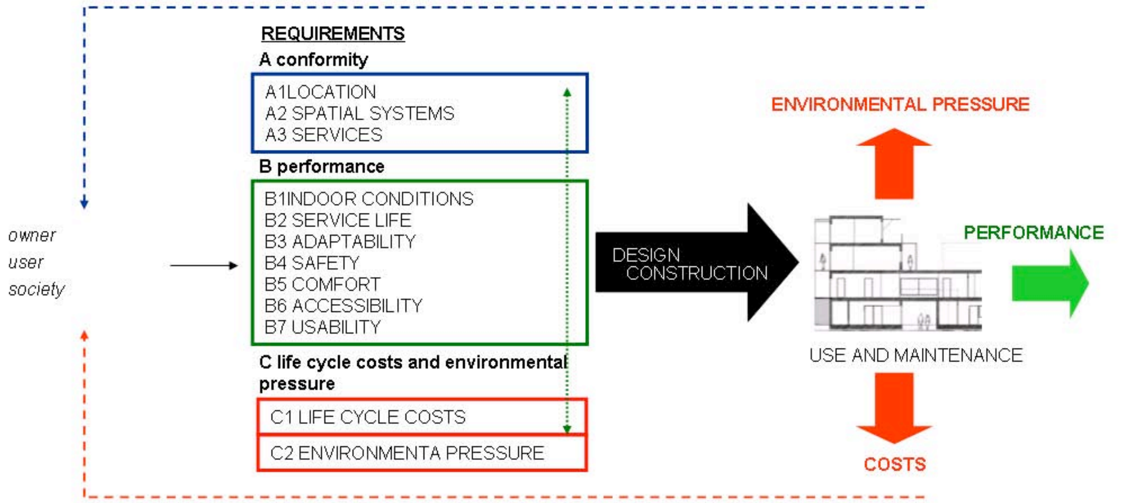


Figure 13: Adaption of performance approach and requirements management in EcoProP software (EcoProP 2004).

Software can be used in

1. A project team session or
2. An individual user can set the requirements.

Team session mode improves quality of selected targets and defined project goals because participants are challenging each other's ideas and selections. Also the commitment for the project increases amongst the team members.

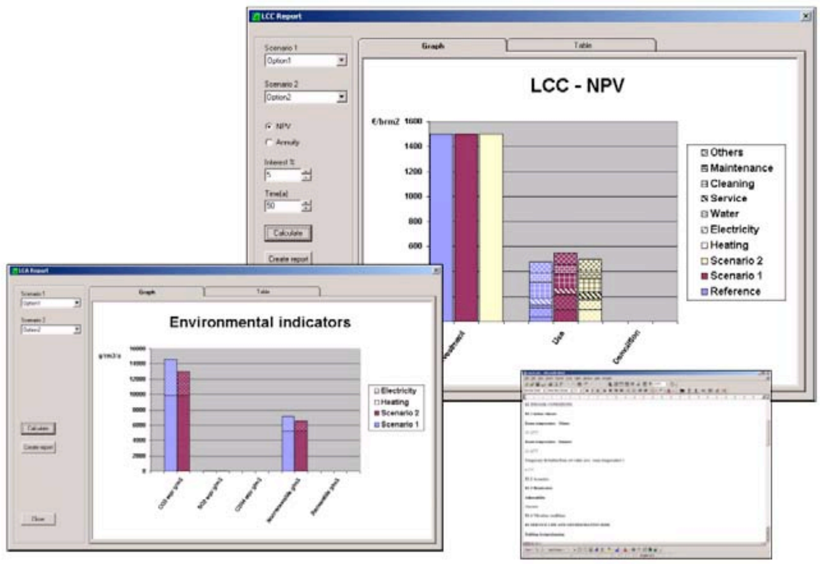


Figure 14: Output from EcoProP software, including life cycle cost and environmental pressure calculations and report (used as an appendix of the design brief) (EcoProP 2004).

Projects where software has been used include various case types like schools, nurseries, residential developments, shopping centres and mostly office buildings. Though EcoProP is not an assessment method, it has already proven similar benefits. Experiences of implementations reveal that it increases discussion, commitment and teamwork. It also verifies that the original needs of the stakeholders get documented as well. Similarly iteration of targets exploits performance requirements to ensure that essential requirements are not eliminated.

EcoProP has proven to be a valuable aid in implementing the performance approach in Finland because the users are 'forced' to think their objectives before ending up into the technical solutions haystack. It has been shown that less effort and less time is required to generate more precise information than the practitioners originally suspected. Some of the practitioners have also noticed that the buildings they operate should have a long, well performing life cycle with low use and maintenance costs.

1.3 Quality Function Deployment

1.3.1 Theory

Quality Function Deployment (QFD) offers a framework enabling prioritisation of objectives and understanding the links between choices and potential conflicts between them and possibilities of using benchmarking. It has been developed for setting specifications and is used in manufacturing industry for product design (Huovila et al. 1997 and Austin et al.1999). QFD is a structured approach that can help a project team represent performance objectives and priorities and then evaluate how and whether these objectives can be met (Rawabdeh, et al., 2001). It allows rigorous requirement analysis, systematic management of requirements during engineering and collaborative iterations for improvement therefore reducing the value loss from the point view of the customer (Koskela, L. and Huovila, P., 1997, Koskela, et al, 1999 and Kamara, et al., 1999). Recent experimentation showed that using QFD helped in thinking about the facility life cycle early in the process; documenting the performance objectives and making transparent decisions thus adding value to the customers (Huovila, P., 1999 and Sarja, A., 2000). Lean function deployment (Tyagi, et al, 2000) and lean design management (Koskela, et al, 1997) are attempts to analyse waste in design and construction then rationalise and re-engineer the process using QFD system framework.

QFD is an engineering method for converting requirements into quality characteristics and for developing product design by systematically deploying the relationships of requirements and product characteristics (Lee, et al, 2000). QFD employs mathematical analysis using a series of matrices, which depend on functional relationships, to arrive at the highest level of quality in producing a product (Maharon, M., 1999). QFD can help a client to define their needs, creating the performance brief based on those needs, designing the building, constructing, maintaining and operating it and finally, demolishing it (Leinonen, et al, 2000). QFD method ensures that the client's expectations are met in a profitable way, that management techniques are employed for maintaining client's requirements and solutions are aiming at the optimisation of the end product (Huovila, et al., 1997 and Kamara, et al., 1999, Leinonen, et al, 2000, Nieminen, et al., 2000 and Rawabdeh, et al., 2001).

1.3.2 QFD Tools

There are certain tools available in the market. One of them is PeBBu tool created in University of Reading. Alternative approach to world of QFD is offered by VTT QFD tool.

1.3.2.1 University of Reading - QFD PeBBu Tool

QFD methodology has been used as the structure and mathematical system to assess the importance of the actions in delivering the required desirable urban features. It provides the decision framework to arrive at the performance specification. At every stage in the decision making process the user can access further information via the embedded hyperlinks. The tool consists of structured lists of desirable space features, performance requirements and state of art examples with relevant hyperlinks to websites helping the user to better understand the context of the selected feature.

Through reviewing relevant literature and carrying website surveys, areas for inclusion in the state of the art in respect of the built environment are being identified. The collection and analysis of the relevant published literature and websites surveys intended for better understanding of the indoor environment problems and regeneration actions. The difficulty with the available information is that the desirable functional space and regeneration actions are implicit within the description of the indoor environment. This is overcome by rigorous search through out the available text aimed at making this essential distinction in order to enable the analysis and the assessment of the performance based indoor environment problem. Software uses an Access database, which consists of structured lists of Desirable Indoor Environment Features, Regeneration Actions and State of Art Examples with links to relevant literature and websites. Methodology has been adopted as a framework as follows.

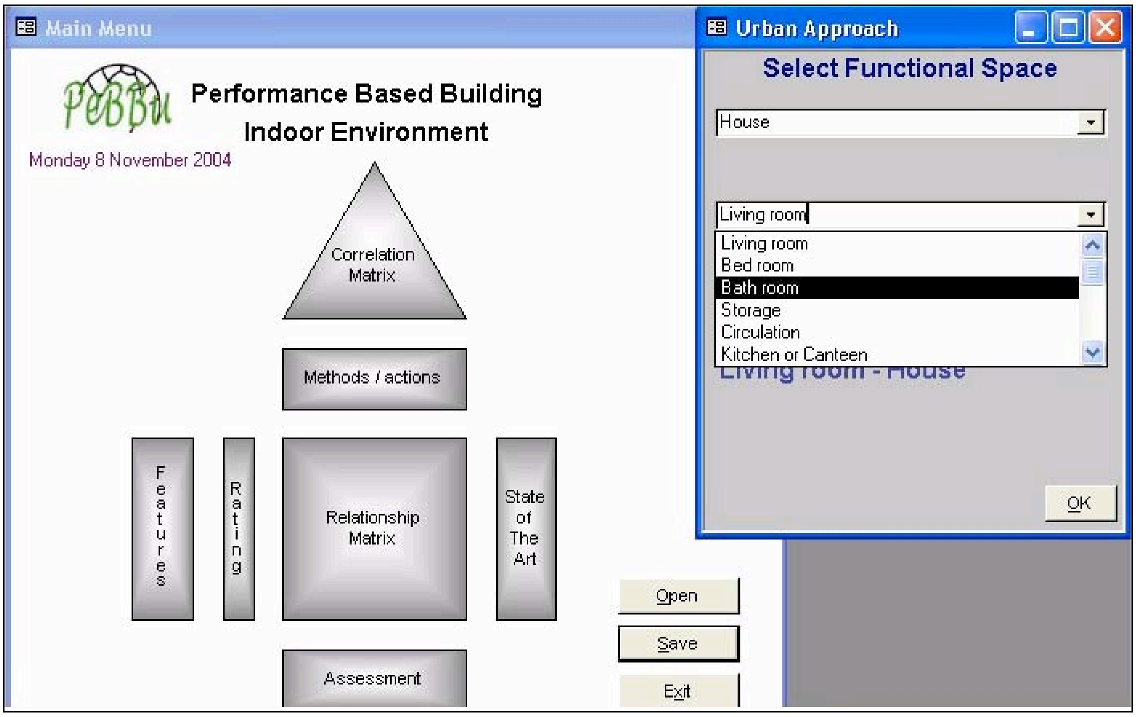


Figure 15: Opening form of QFD software in University of Reading regarding Indoor environment.

Entry to decision-making framework

The opening form shows the structure of the steps to take. Users start by selecting an urban approach from pre-designed modules: House containing separated spaces such as living room, bed room and bath room. The user has the possibility to view, discuss and change the suggested module parameters. The PeBBu help system can be consulted by clicking the Help button at the Main Menu.

Choosing required features

Desirable features of the loaded indoor environment are selected from the form. They are grouped into five categories: Economic, Physical, Environmental, Social, and Training and Education. It's possible to select, deselect or add new features to the default list. Features can also include references like links to certain websites or knowledge bases.

Ranking desired features

Once the desirable features are identified, the user is allowed to set an importance ranking for each feature. This is in effect a prioritisation of the importance of each aspect in the defined need. The importance rate is set on a five-point scale from very low to very high. The ranking is subjective and will vary according to the user perceptions and criteria.

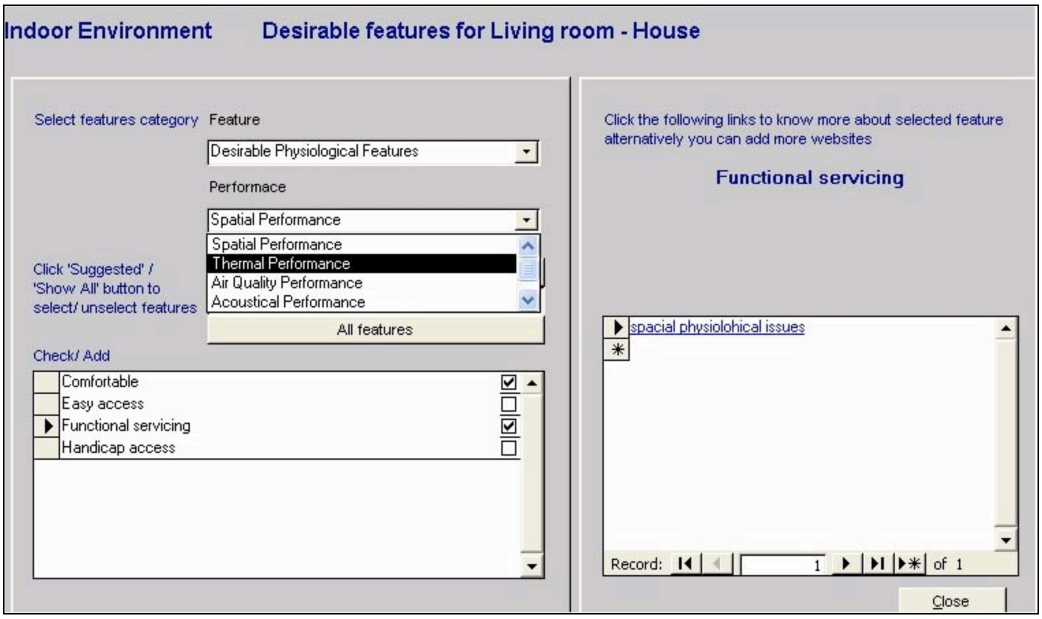


Figure 16: Desirable features for living room in House.

Benchmarking quality of desired features

With a system that is based on the user's perceptions it is useful to have a reference point that is either ranked by the user or set by an independent person. Thus by benchmarking the desirable features against other state of art examples ranked previously, enables the communication of values from one group to another. The quality rate is set subjectively on a five-point scale from very low to very high. Software stores every selection to database.

Selecting actions to meet desired features

For each of the desired features selected above there will be a number of ways of providing a solution in terms of actions. These actions form the basis of the performance specification. Each action in the list includes more information. Functionality actions are grouped into five categories: Economic Development, Physical Improvement, Environmental Actions, Neighbourhood Strategy, and Training and Education.

Correlation between actions

The Correlation Matrix indicates where there is either support from the actions working in concert with each other (the positive relationship) and where they are in conflict with each other (the negative relationship). Correlations are presented in a matrix with correlation strengths of: 9 = Very Positive, 3 = Positive, 0 = Neutral, -3 = Negative or -9 = Very Negative. User can also use "Rationale" to define users record the decision-making reasoning for the strength given to the correlation between each pair of actions to help managing the evaluation and feedback process.

Satisfying rules between desirable features and actions

The final stage is to determine how well each of the actions that have been selected meets the criteria of each desirable feature. For each feature selected in the relationships matrix is established. The strength of the usefulness of the action is expressed by (scale 0, 1, 3 or 9 is very strong). The strengths of the relationships are subjective according to the user's understanding of the issues. Text area labelled "Rationale" is a verbal clarification.

By double-clicking on a feature or an action, a pop up window appears to show the relevant list of links to literature and websites. Also, when a relationship between a feature and an action is selected, a relevant list appears at the bottom-right of the form, of links to pages that shows literature and websites of the state of art examples of the selected relationship. Users can surf these websites or add more links to the list.

Assessment Form and Reports

The selected actions are scored taking into account the strength of their relationship to the desirable features and the features' importance and quality rates. Actions are also scored according to their feasibility taking into account their correlation strengths. The Assessment follows the actions in order of their scores. The actions of highest importance scores and lowest feasibility rate are displayed first as these are the most problematic situations, which need more attention so that trade offs could be made and the conflict could be solved.

Following detailed reports are available

- Importance assessment report: Actions are listed in descending order of their importance scores and grouped with features that produce 45 importance points, i.e. very important feature with very strong relationship to the action in consideration. Contains also reasoning behind the high score of each relationship.
- Competitive assessment report: Actions are listed in descending order of their quality scores and grouped with features that produce 45 quality points, i.e. very high quality feature with very strong relationship to the action in consideration.
- Performance requirements report: Features are grouped and listed according to their importance rating starting with the very important features (score 5).
- Technical feasibility report: Actions are listed in ascending order of their technical feasibility and grouped with actions that have very negative correlation (-9).
- Quality requirements report: Features are grouped and listed according to their quality targets starting with the very high quality features (score 5). This report shows as well the decision-making reasoning behind the selected quality standard.


Performance Based Building

House
Living room

Performance Requirements

Features of 5 Importance Rating

Acceptable Noise Level

Noise control is of high importance as it can be a particular problem , and background noise levels are high in many areas. Whilst job opportunities and leisure facilities should be maintained, this must be reconciled with the need for satisfactory living

Air Quality

Air Quality means clean air for one or more of the following pollutants: ozone, carbon monoxide, particulate matter, and nitrogen dioxide. Atmospheric pollution in cities is receiving more and more attention. It has a strong impact upon our daily life and

Figure 17: Performance requirements report.

Summary

A proof of concept tool has been produced that is now ready for trial use. The underlying knowledge base is constantly being upgraded as new information and websites are developed. In practice this needs to be an ongoing exercise. The tool provides a generic starting point for adaptation to a specific use by a particular user. Each user has a different level of knowledge and appreciation and this is accommodated by the ease of access to external knowledge sources and the ability to set personal performance criteria. Where performance specifications are more accessible the output of this decision framework could be used to structure and even produce a performance specification complete with priorities. The advantage is that this approach allows further refinement of the specification through levels from outline to detail whilst still maintaining the original concepts and values intact.

1.3.2.2 VTT - QFD Tool

VTT has adopted generic and simple approach in tool development for QFD method (Akao, Y. 1969). It is used in a form of House of Quality matrices consisting of requirements (in rows) and properties of solutions (marked in columns). Criteria are expressed in a form of performance requirements and they are given weights (scale 1 to 5) depending on their importance. The potential design solutions are then created from properties and their correlation with the requirement is given (scale 0, 1, 3 or 9). The QFD spreadsheet tool summarises numeric values of the properties in the bottom of matrix by multiplying the correlations with their weights so that high values indicate high priorities. The user may then select the most important properties as a basis for next phase of development.

The tool can be used in a half-day brainstorming session to set design guidelines for a building to be constructed. The House of Quality matrices is formed to judge how well the original design criteria and technical solutions meet customer requirements. Brainstorming session gathers experts of all desirable fields together to solve problematical issues like: to share common understanding of the performance-based objectives of the building, to prioritise the project objectives and to strive for innovative design solutions which meet these objectives.

VTT	PHASE 1 Properties / Requirements	adaptability	resale value	indoor conditions	attractiveness	economy	autonomy	friendliness to the environment	futurity	habitability	respond to the environment	good indoor climate	constructability	identity	total ecology	architecture	simple user interfaces	recyclable fair house	transferability	dismountability		Importance factor
functionality	**Utilisability**	9	9	9	9	3	9	3	0	9	0	9	0	1	1	0	9	3	1	0		5
	Adaptability	9	3	0	9	3	1	9	3	9	0	0	1	1	9	0	1	9	9	9		2
	Maintainability	3	3	3	3	9	9	9	0	9	0	3	0	0	9	1	3	1	1	1		2
environmental loading	Operation	9	3	9	3	9	9	9	1	1	9	9	0	0	9	0	0	0	0	0		4
	Construction	0	0	0	3	3	0	9	0	0	0	0	9	1	9	1	0	9	9	9		2
resource use	**Energy**	9	3	9	3	9	9	9	9	0	9	9	0	3	9	0	0	1	1	1		5
	Water	9	1	0	1	3	9	9	3	1	0	0	0	0	3	0	1	0	0	0		1
	Materials	3	9	9	3	9	1	9	9	9	0	9	9	9	9	3	0	9	9	9		1
life cycle cost	Investment cost	9	9	3	3	9	3	0	0	0	3	3	9	1	0	0	1	3	3	3		3
	Operating cost	9	9	1	3	9	9	9	3	0	3	1	0	3	3	9	9	3	3	3		4
	Maintenance cost	9	9	3	9	9	9	9	9	0	9	3	0	3	3	9	3	3	3	3		2
indoor quality	Acoustic comfort	9	9	9	9	0	0	0	9	9	0	0	3	3	0	9	0	0	0	0		2
	Thermal comfort	9	9	9	9	0	0	3	9	9	9	9	3	3	0	9	3	0	0	0		3
	Lighting	9	9	9	9	3	9	3	9	9	9	0	3	9	1	9	1	0	0	0		4
	Indoor climate	3	9	9	9	0	0	3	9	9	9	9	9	9	1	0	0	0	0	0		5
architecture	Architecture	9	9	9	9	9	3	0	9	9	3	0	9	9	0	9	1	3	3	3		3
	Weight factor	393	355	322	307	285	273	258	250	248	246	241	182	180	179	169	118	112	102	97	0	4317
	Weight factor %	9 %	8 %	7 %	7 %	7 %	6 %	6 %	6 %	6 %	6 %	6 %	4 %	4 %	4 %	4 %	3 %	3 %	2 %	2 %	0 %	100 %
	Votes	4	1	3		2	1	3			1		2		4	4	1	1				
	Selected	x		x		x		x					x			x						

Figure 18: Design objectives for a housing project, phase I.

The first matrix shows the selected main objectives of a housing project (adaptability, indoor conditions, economy, environment friendliness, constructability and architecture) taken as a basis for building design. The second matrix presents the structured approach in the design process based on the selection made in phase I.

PHASE 2 — Properties / Requirements	SPACE	PROCESS	STRUCTURES	MATERIALS	ENERGY	EQUIPMENT	Importance factor (P1
adaptability, simple interfaces, re-usable fair house	9	9	9	3	3	1	**3**
indoor conditions, responds to the environment	9	9	9	9	9	9	**4**
economy, resale value	9	9	9	9	9	9	**1**
environmental,autonomy, total ecology	9	3	9	9	9	9	**5**
constructability	1	9	3	1	1	1	**3**
architecture	9	9	3	9	1	0	**2**
Weight factor (P1)	138	134	133	120	104	95	**724**
Weight factor %	19 %	19 %	18 %	17 %	14 %	13 %	**100 %**

Figure 19: Design objectives for a housing project, phase 2.

1.4 Multi Criteria Decision Making

There is often a situation when complexity hinders unanimous decision making leading to conflicts. In second chapter of this report the possibilities for performance classifications (i.e. Check lists) were introduced. Requirements management in chapter 3 brought us closer to built environment and immediate surroundings. This chapter provides us with guidelines to multi criteria decision making. In special literature decision making is basically called to decision analysis. As a whole, field of decision analysis has significant value in present project culture. The number of practitioners has grown (Hämäläinen 2003) and negotiations are taking the most out from e-commerce applications (Lomuscio et al. 2003). Internet is already a significant DSS software delivery channel.

1.4.1 Theory

History of decision problems dates back many hundred years. For example many decision problems have been introduced as paradoxes. This report depicts the concept of value tree analysis. First, three different parties and roles in decision making are identified (HUT 2002)

1. Decision maker, DM (empowered to make decisions, in most cases also responsible for consequences)
2. Decision analyst, DA (helps and advices DM in finding the most appropriate decision alternatives and in facilitating the decision making process)
3. Stakeholder (has an interest in decision under consideration).

According to authors, DMs and stakeholders constitute the main body of meetings behind the conclusions in construction and real estate business. Role of DAs has thankfully advanced and grown. Specialist, experts and consultants participate to decision making process actively. The objective of decision making process is to offer a structured way for solving the problem and verify that all matters have been taken into consideration.

Generally, phases of value tree analysis are (HUT 2002)

1. Problem Structuring
    - Defining the Decision Context
    - Identifying the Objectives
    - Generating and Identifying Decision Alternatives
    - Creating a Hierarchical Model of the Objectives
    - Specifying the Attributes
2. Preference Elicitation
3. Recommended Decision
4. Sensitivity Analysis

Problem structuring provides an executing body with better understanding of the decision problem. Simultaneously objectives, relations and alternatives have been discussed. Preference elicitation is targeted to measure and estimate a set of objectives. Typically this is an iterative process where different weighting methods are taken into consideration. Recommended decision is verified in sensitivity analysis that points out how individual attributes effect on whole solution. Practically this means probability ratings revealing causes when individual attributes value is raised or reduced. Decision making process also procures common language for project communication.

Next section presents one weighting method for evaluating probabilities of multiple attributes. This weighting method is Analytic Hierarchy Process. After theory a software tool supporting method is presented and utilised to AHP case comparison.

1.4.2 Analytic Hierarchy Process

Theoretical background of Analytic Hierarchy Process (AHP) is represented literature by Saaty (1986). This section relies on broader foundation. Saaty's method has been further developed. (Saaty 1986; Saaty et al. 1994; Golden et al. 1989; Salo et al. 1997; HUT 2002). AHP is based on paired comparisons and the use of judgement preference ratio scales. In the standard form, alternatives are not differentiated from the attributes and objectives but are treated as a bottom level of the hierarchy. First, DM gives ratios for each pair comparison of sub-objectives, attributes or alternatives.

$$r_{ij} = \frac{w_i}{w_j} \qquad (1)$$

Pair comparisons are simplified with fixed values (i.e. ratio description in comparison r_{ij}). Fixed values show relations in number scale (1-to-9). Table 1 illustrates number scales, balanced values and descriptive verbal statements.

Table 1: AHP Comparison Scale (HUT 2002).

Verbal Statement	Scale 1-to-9	Balanced
Equally important	1	1.00
-	2	1.22
Slightly more important	3	1.50
-	4	1.86
Strongly more important	5	2.33
-	6	3.00
Very strongly more important	7	4.00
-	8	5.67
Extremely more important	9	9.00

Pair comparisons are core of AHP. Therefore, a particular attention is pointed out to scale selections. Each attribute is compared with others under same objective (i.e. branch). Preference ratios are stored to a comparison matrix.

$$\mathbf{A} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{nn} \end{bmatrix} \quad (2)$$

Diagonal r_{ii} elements in comparison matrix A are equal to 1. Only upper triangular matrix is stored; lower triangular matrix values inherit from values gathered.

$$r_{ij} = \frac{1}{r_{ji}} \quad (3)$$

The weights are estimated from w_i by normalising the elements with the largest eigenvalue (λ_{max}) of the matrix A.

For n weights (values), the DM gives n(n-1) estimates (preference statements). In Consistency Index (CI) calculation comparison matrix A is consistent if and λ_{max} = n. Consistency index indicates an average variation range of matrix A.

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (4)$$

Consistency Ratio index (CR) defines the applicability of the weighted estimates given.

$$CR = \frac{CI}{CI_{aver}} \quad (5)$$

In the formula CI average subscribes over a large number of random matrices of n elements. Entries of CI_{aver} derive from the scale 1/K, 1/(K+1),..., 1,..., K-1, K, where K is a positive constant giving the bounds for the real weights.

To be exact, the same comparison scale should be used both in the assessment of the actual comparison matrix and generation of random matrices (Salo et al. 1997). Alternative solution is a scale-invariant consistency measure.

$$CM = \frac{2}{n(n-1)} \sum_{i>j} \frac{\bar{r}(i,j) - \bar{r}(i,j)^{-1}}{\left[1 + \bar{r}(i,j)\right]\left[1 + \bar{r}(i,j)^{-1}\right]} \quad (6)$$

Where

$$\bar{r}(i,j) = \max_{k} a(i,k)a(k,j) \quad (7)$$

is the extended bound of the element a(i, j) in the row i and column j of the comparison matrix (Salo et al. 1997). Finally, given preference ratios are consistent if the value of CM is less than 0.2. If the figure is larger the preference statements need further modification.

In AHP method, a change in the set of alternatives may alter the existing order between the alternatives, even if the original valuations are not changed. The phenomenon is called rank reversal. The rank reversal effect is widely seen as a result of the value normalisation, in which the sum of values under an attribute equals one. Rank reversal can be avoided by using value functions and normalisation in which the value 1 is given to the best alternative and 0 to the worst alternative. Others are rated in between. (Belton et al. 1983)

1.4.3 Decision Analysis Tools: Web-HIPRE Software

This section focuses on tools supporting multi criteria decision analysis especially AHP method of pair comparisons. There are many commercial and freeware tools for decision analysis available in the market. Lists have been published, for instance by Maxwell (2000).

One of the public sites is Decisionarium (http://www.decisionarium.hut.fi) which offers tools for individual decision making and group collaboration. Amongst other methods like SMART, Web-HIPRE software includes also AHP method.

Web-HIPRE (Hämäläinen et al. 1998; Mustajoki et al. 2000) is software for supporting different phases of multi attribute decision analysis process, i.e. modelling the problem, weighting of attributes, evaluation of alternatives and analysis of the results. The software is carried out as a Java implementation.

Interface is graphical and the user can carry out all the phases. It supports different weighting methods used individually or in parallel in a comparison case. Supported weighting methods are: SMART, SWING, SMARTER and AHP.

Software enables integration of individual weighted models to one group model with the calculation of arithmetic means. Sensitivity analysis reveals and explicates meanings of single parameters. Group model is implemented through internet. Therefore, its components can be linked to web pages containing relevant material. Group model highlights a discussion of e-commerce applications. Software is freely downloadable for non-commercial academic use and preliminary testing in commercial use. Internet site: http://www.hipre.hut.fi .

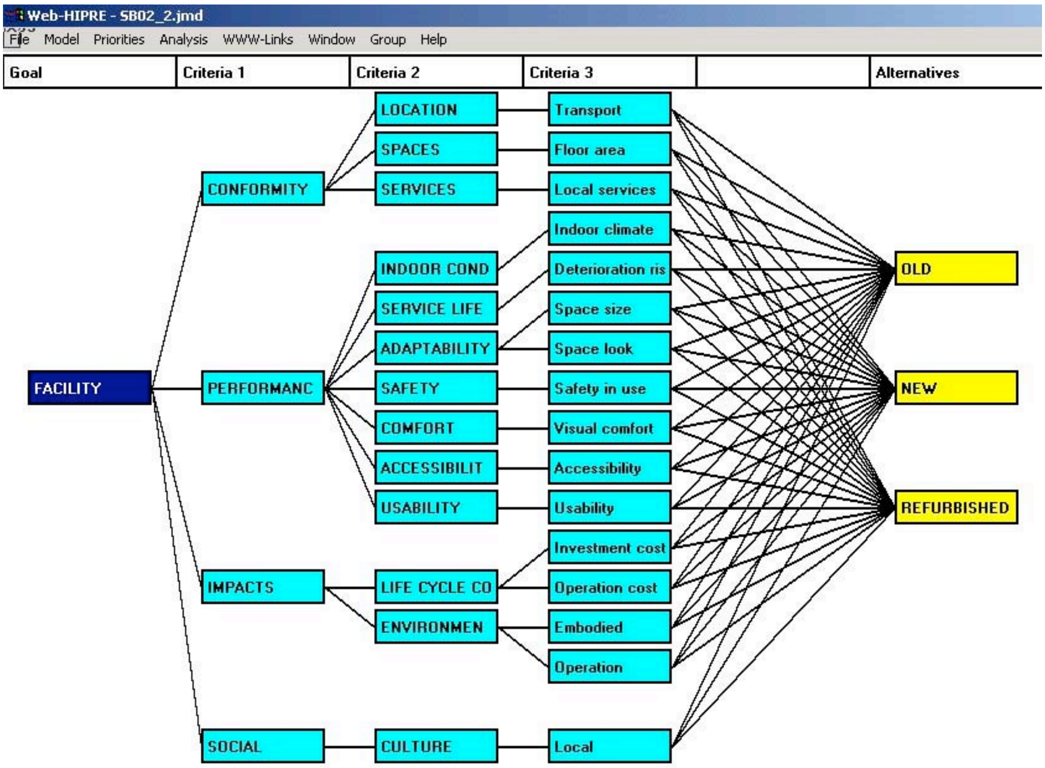


Figure 20: Building properties hierarchically modelled in Web-HIPRE – and linked with three alternative solutions.

AHP Comparison Case

Web-HIPRE software was used to facilitate comparison case where AHP weighting method was used. The objective is to clarify structure of AHP. In this context Web-HIPRE suits well to purpose with visual interface and AHP weighting method.

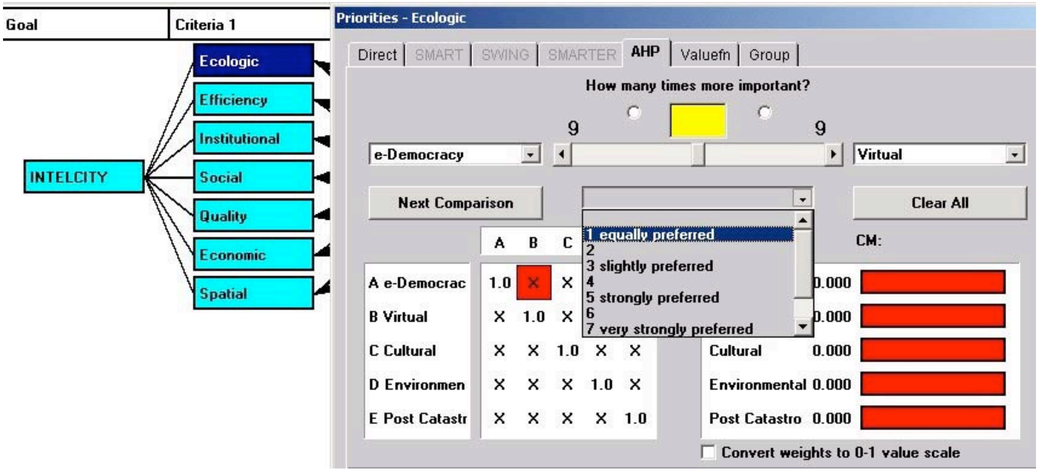


Figure 21: AHP pairwise comparison procedure in Web-HIPRE.

Decomposition of hierarchical structure is carried out in top-down manner. First, upper branches are defined. Then objectives in different levels are described and finally individual attributes.

Weighting of the objectives or attributes under compensation branch follows path described earlier, each individual value is compared with others under same branch. Preference ratios are presented with fixed values (1-to-9). After setting an adequate value next comparison button is pressed. When all fixed values are set the CM shows is they are consistent enough.

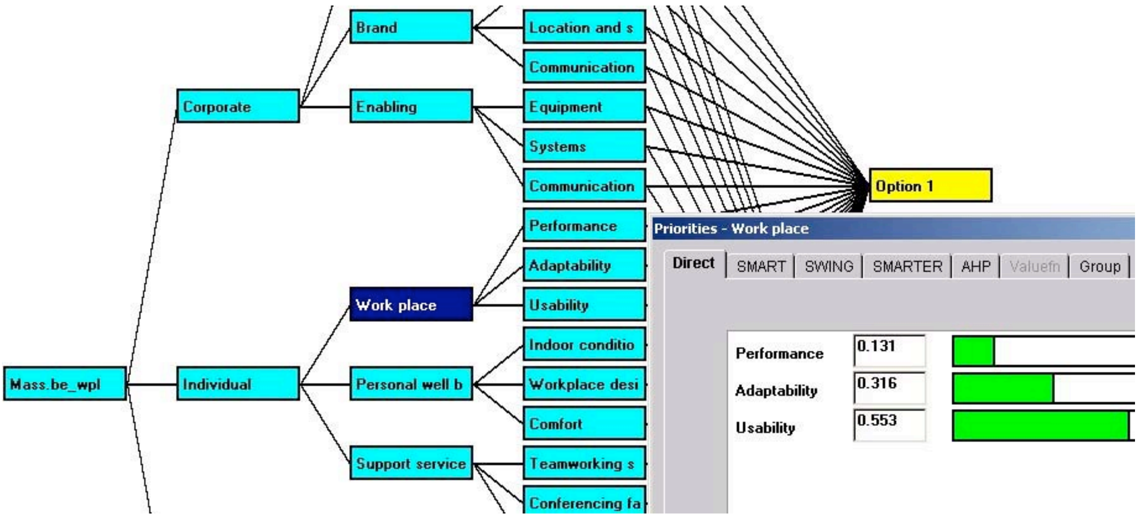


Figure 22: Direct (visual) weighting in Web-HIPRE.

Weighting values are automatically normalised and shown in component priorities window. They are in text form and easily copied out to other software tools. In this instance the sensitivity analysis is not presented because the main focus is concentrated on AHP weighting method.

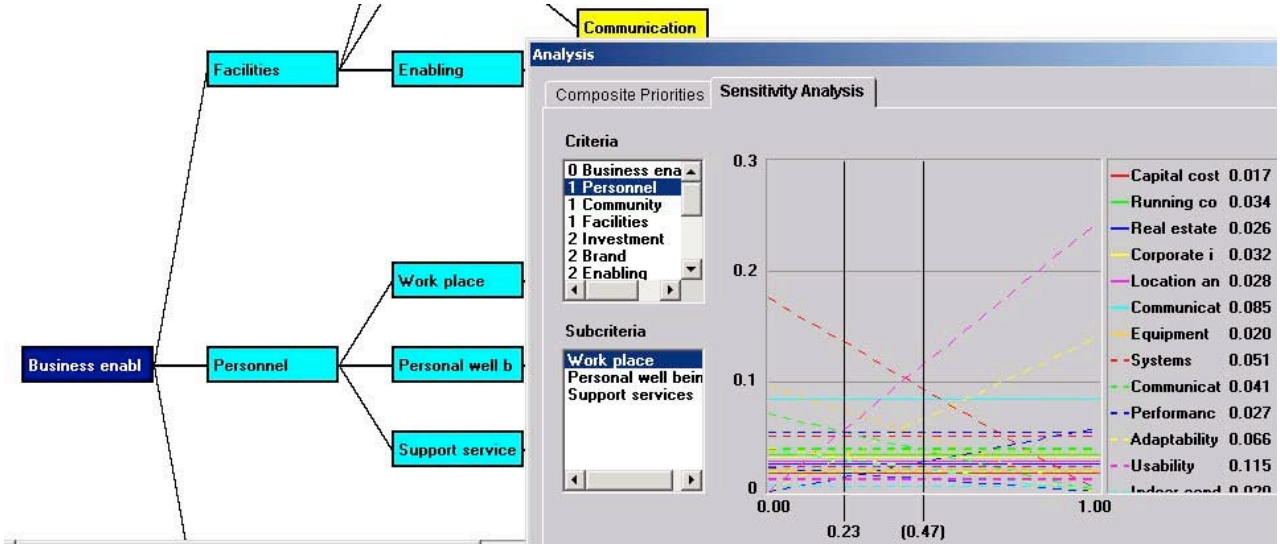


Figure 23: Sensitivity Analysis in Web-HIPRE.

1.5 Design Structure Matrix

Reducing lead time, optimizing process and improving the quality of data transfer between process phases are everyday practice in business. Especially, more attention has been paid for ensuring reliable and required input data for tasks following, specifically taking cognizance of dependencies or strong relationships. Nature of projects is getting more complex and sophisticated tools to clarify system analysis and project management are needed. The Design Structure Matrix, DSM, is a tool for system analysis and project management. It is also recognized with other names: Dependency Structure Matrix, Problem Solving Matrix (PSM) and Design Precedence Matrix.
History of the matrices dates back to 1970s and 1980s. One of the pioneers was Donald Steward who introduced particular DSM structure in 1981 (Steward 1981). Concept got more attention and publicity in 1990s and has been further developed by numerous authors.

1.5.1 Theory

The theory described in dsmweb.org has been taken to a baseline of this report (DSMWEB 2004). In general, systems can be analysed by structure and semantics. Semantics fill the gap of structure not telling how components interact with others and answers simultaneously to questions ‘why and how the parts affect’ (Steward 1981).

The DSM concept has two standpoints; it can be used for system analysis and project management purposes. First, it is a system analysis tool with compact and clear representation of a complex system and a capture method for the interactions/ interdependencies/ interfaces between system elements. It highlights a visual presentation for relationship modelling and brings separate pieces together. It also reveals key information flows and sets targets to process analysis and re-engineering. Therefore, it enables discovering previously unknown patterns from product and organizational architecture guiding simultaneously human resource management.
Second, it is a project management tool that provides a project representation allowing feedback and cyclic task dependencies. Complex information flows are simplified. It helps entire project team to understand the big picture. Project manager is also provided with possibility to trace impacts of decisions and specify a

common point of view for entire project team. It is extremely important since most engineering applications exhibit such a cyclic property. DSM results in an improved and more realistic execution schedule for the corresponding design activities.

Structure and Semantics

Directed graph is used to describe the system structure. Binary matrices can represent the presence or absence of a relationship between building blocks. Three basic building blocks for description of relationships amongst system elements are called parallel (or concurrent), sequential (or dependent) and coupled (or interdependent). In terms of the modelling, coupled elements bring most of the complexity to systems.
In DSM matrix the system element names are placed down the side of the matrix as row headings and across the top as column headings in the same order. If an edge between nodes exists, then the value of element is unity (or marked with an X). Otherwise, the value of the element is zero (or left empty). In the binary matrix representation, the diagonal elements of the matrix don't describe the system, they are usually either left empty or blacked out.

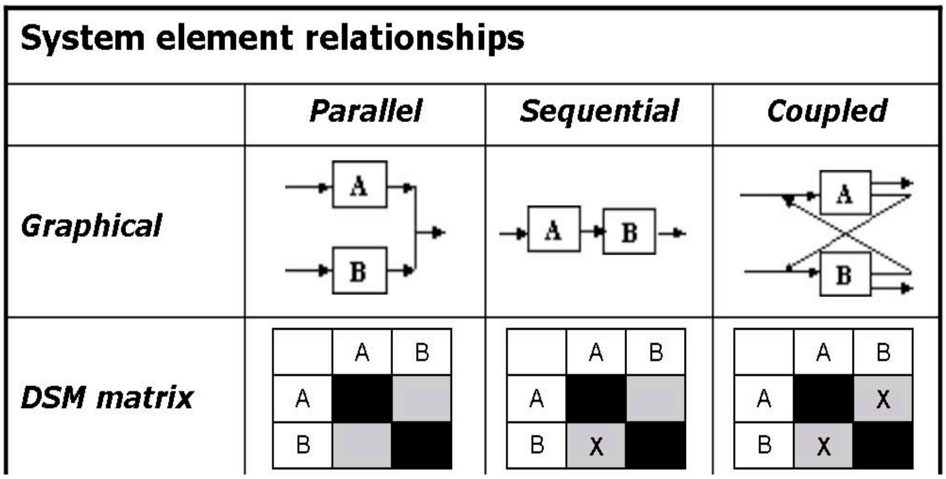


Figure 24: System element relationships in basic DSM presentation. (adopted from DSMWEB 2004)

If the system consists of a set of tasks to be performed, the off-diagonal marks in a DSM row represent the tasks where output is required to perform the task corresponding to that row. Similarly, a DSM column reveals information flows between tasks. Altogether, marks below the diagonal means forward information transfer to later (i.e. downstream) tasks. Below diagonal marks are forward marks or forward information links. Marks above the diagonal depict information flow from later to earlier tasks (i.e. feedback mark) which indicates that an upstream task is dependent on a downstream task.

Nevertheless, the information flows in coupled systems are intertwined: element A has an influence on element B and vice versa. Additionally they can establish a circuit. Sometimes X for edge between elements is replaced with a set of letters or other marks indicating temporal sequencing (i.e. schedule) or strength of dependency. For example letter S might indicate that task B starts when task A finishes. There are several DSM matrix data types adaptable to various purposes

- Component-based (System architecture, engineering and design)
- Team-based (Organizational design, interface management, team integration)
- Activity-based (Project scheduling, activity sequencing, cycle time reduction)
- Parameter-based (Low level activity sequencing and process construction).

Typically matrixes are asymmetric but in some special cases they can also be symmetric. Like mentioned earlier, the rows reveal input dependency and the columns output dependencies. Upper-diagonal elements represent the probability of having to loop back (i.e. iteration) to earlier upstream activities after a downstream activity was performed (Smith et al. 1997). Lower-diagonal elements can represent the probability of a second-order rework following iteration (Browning et al. 1998). DSM methodology suggests the manipulation of the matrix elements such that iterative behaviour is removed from the matrix, or at least minimized. One solution for manipulating the structure is an algorithm called partitioning. Elements are denoted by letters (A-K) in the row headings. Same element order appears also as column headings.

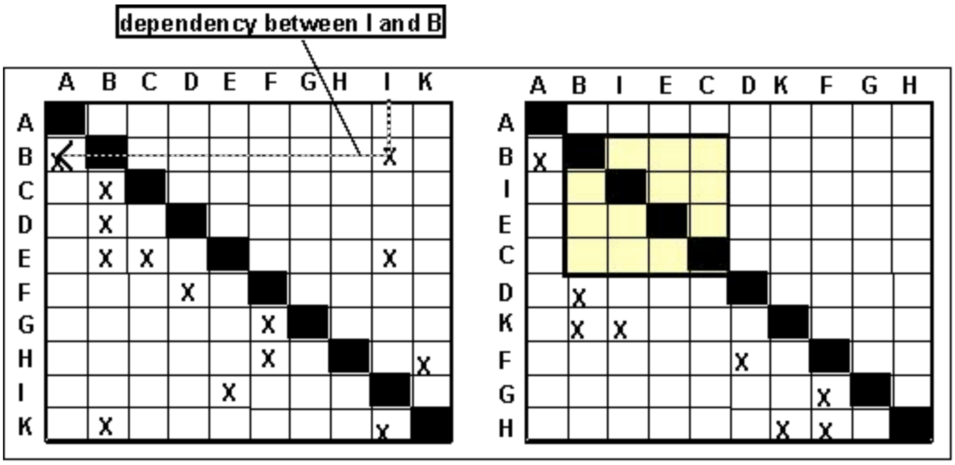


Figure 25: Sample of Design Structure Matrix methodology, DSM (Leinonen 2002).

It's also possible to sort out elements to chunks (i.e. modules). Practically this means that the algorithm sorts the elements such that the analyses over potential product chunks (modules) are enabled, interfaces between them are illustrated and integrative components noticed. In DSM matrix these chunks can be described with other colour.

Partitioning

In partitioning the rows and columns are reordered such that the new arrangement matrix contain as few feedback marks (i.e. marks above the diagonal) as possible. Basically it's a transformation from upper to lower triangular form. In complex engineering systems, it is highly unlikely that simple row and column manipulation will result in a lower triangular form. Therefore, the objective is to move all marks as close as possible to the diagonal. This reduces the number of system elements involved in iteration cycle and results ultimately to faster development process.

1.5.2 Process Steps

Successful use of the DSM method is determined by the appropriate system decomposition and by the accuracy of the dependence relationships collected. Therefore, system and elements need to be carefully studied. Decomposition reaches highest fidelity if a group of managers and experts from different functional groups of an organization have collectively defined the structure and semantics.

The decomposition can be either hierarchical or non-hierarchical. Latter is sometimes defined to network decomposition, where hierarchy isn't evident. When the structure is hierarchical, the system is divided from elements to sub-elements and finer components. Once the appropriate system elements or set of activities that comprise a project have been identified, they are listed in the DSM as row and column labels in the same order. The elements within the matrix are identified by the group of managers and experts who define system structure and semantics.

Process steps include

1. Interview engineers and managers
2. Determine list of tasks or parameters
3. Ask about inputs, outputs, strengths of interaction, etc
4. Enter marks in matrix
5. Check with engineers and managers to verify/comment on DSM.

Without a dispute, the process decomposing enhances the whole process understanding. DSM is a powerful process structure modelling method which simultaneously enables process studying and improvement opportunities (Huovila 1995).

If there are blocks detected, those illustrate coupled relationships. DSM helps to find the right order of tasks, which can be sequential and parallel or coupled. Sequential and parallel tasks are easily put to right order. Blocks can form larger chunks and concurrent engineering techniques can be used to achieve needed co-operation between tasks, persons and organizational units (Huovila 1995).

This gives a solid base to plan schedule and change management. There is a possibility to collect up a list of people to be informed in case of certain design changes. The effect of individual people to wholeness can also be examined. And what comes to tasks, the most critical one in terms of information flows can be detected and taken into cognizance.

1.5.3 DSM Tools

There are also many commercial and freeware DSM tools available in the market. Besides tools the development during past years has also been directed to calculation algorithm improvement. Further information of tools is available at: http://www.dsmweb.org/DSM_tools.htm

One of the existing tools in the market is DSM System which was developed at late 1990s in Technical Research Centre of Finland (VTT). It is a Microsoft Excel application for complex design process management with DSM function control drop-down-menu. Therefore, the presentation and straightforward use for development purposes are easily applicable. DSM System was used also in Demonstrator case defined in following section.

DSM Demonstrator Case

This section portrays usage of DSM in Demonstrator case, presented in FutureHome project in 2002 (Leinonen 2002). First, the DSM analysis of the product architecture started with structure element definition. There were two different component types: single site assembly element or single factory assembly element, the earlier was selected. Second, the mapping of relationships was made. The successors and predecessors of each element in assembly process were detected. After this the duration of each assembly task was set.

The largest part to be transported to the site as a single entity was the core 3D module implementing the developed concept and corresponding technical solutions of the FutureHome project. Other components included wall elements, large floor cassettes, columns and one balcony. Creating the list of components was a straightforward task, which was based on the drawings.

Then, the DSM matrix was optimized for the purpose to find out possible chunks and integrative components between. Finally, the results were analysed and improvements to the product architecture recommended. The outcome of sequences and durations was exported to MS Project scheduling software including also determined critical path.

DSM Analysis

There are two types of product architectures: the components are connected others through integrative components (hierarchical structure) or large part of the components are connected to others directly (network structure). Demonstrator case has hierarchical structure with 3D modules and floor cassettes as integrators.

Architecture of first two floors is fairly independent. Change on the 3D module on the second floor has to be considered. 3D module is the most complicated and interdependent module of the demonstrator, therefore detailed plans are required. It contains many possible secondary modules such: staircase, kitchen equipment and fittings, shaft and bathroom which are delivered by different suppliers. Structure modularity is highlighted and secondary modules are assembled in the factory to 3D module.

Results and Improvements

Normally the assembly process is planned by bar chart schedule tools like MS Project. Assembly process was planned starting from analysing the dependencies between the components. If the component A has to be assembled before the component B, using the DSM analogy it means that A provides input to B. In this case, DSM matrix of the product architecture isn't symmetric. Durations were added due to bar chart export. The DSM matrix optimization used partitioning method. The outcome includes so little iterations (i.e. upstream components) as possible. Additionally, DSM can facilitate cycle time reduction possibilities (Browning 1998).

For the management of assembly it is vital to know the critical path of the process. Critical path tasks delay automatically whole project in case of disturbances. In the future it might be possible to define product development team and do product architecture mapping to ensure information transfer between teams (Sosa 2000).

ID	Activity		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
ID4	Ground floor wall 2	1	1	S	S																															
ID5	Ground floor wall 3	2	S	2		S																														
ID3	Ground floor wall 1	3	S		3	S																														
ID2	Ground floor 3D module	4		S	S	4	S	S										S																		
ID6	Ground floor wall 4	5				S	5		S																											
ID10	Ground floor wall 8	6				S		6		S																										
ID7	Ground floor wall 5	7					S		7		S																									
ID9	Ground floor wall 7	8						S		8	S																									
ID8	Ground floor wall 6	9							S	S	9																									
ID11	Ground floor column 9	10										10	S		S																					
ID24	1st floor column 9	11										S	11	S	S																					
ID40	2nd floor column 9	12											S	12	S																					
ID28	1st floor terrace cassette	13										S	S	S	13			S																		
ID16	1st floor wall 1	14														14	S	S																		
ID17	1st floor wall 2	15														S	15		S																	
ID15	1st floor 3D module	16				S									S	S		16	S	S	S							S								
ID18	1st floor wall 3	17															S	S	17																	
ID19	1st floor wall 4	18																S		18		S														
ID23	1st floor wall 8	19																S			19			S												
ID20	1st floor wall 5	20																		S		20	S													
ID21	1st floor wall 6	21																				S	21	S												
ID22	1st floor wall 7	22																			S		S	22	S											
ID27	1st floor balcony	23																						S	23											
ID32	2nd floor wall 3	24																								24	S	S								
ID31	2nd floor wall 2	25																								S	25		S		S					
ID29	2nd floor 3D module	26																S								S		26	S	S		S				
ID38	2nd floor internal wall 10	27																									S	S	27							
ID33	2nd floor wall 4	28																										S		28			S			
ID30	2nd floor wall 1	29																									S				29			S		
ID39	2nd floor internal wall 11	30																										S				30			S	
ID34	2nd floor wall 5	31																												S			31		S	
ID37	2nd floor wall 8	32																													S			32		S
ID35	2nd floor wall 6	33																														S	S		33	S
ID36	2nd floor wall 7	34																																S	S	34

Figure 26: DSM matrix with inter-disciplinary tasks identified. (Leinonen 2002).

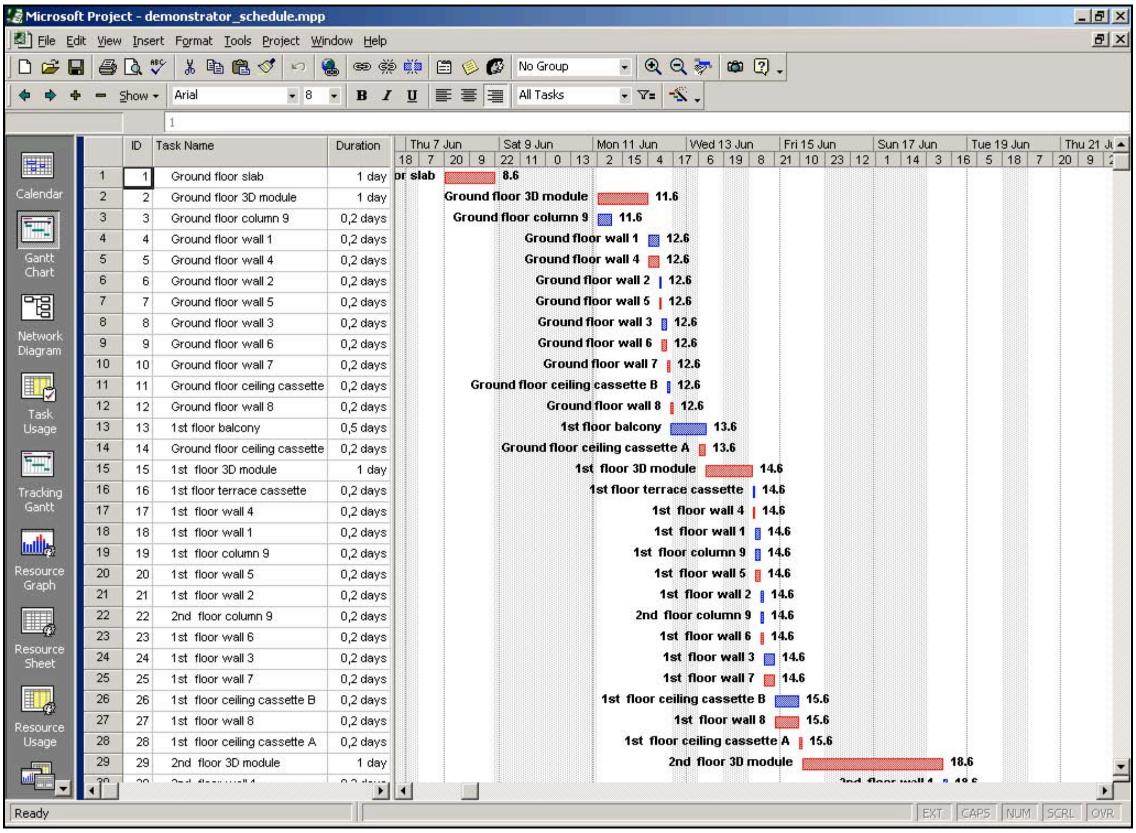


Figure 27: Schedule including the critical path (Leinonen 2002).

1.6 Post Occupancy Evaluation

Post Occupancy Evaluation (POE) is recognized and valued as a process that can improve, and help to explain, the performance of the built environment (Preiser 1988). Briefly, it's a process of evaluating buildings in a systematic and precise way after they have been occupied for some time (Zimring et al. 1980; Preiser et al. 1988; Gonzales et al. 1997). It is also characterised by a formal and comprehensive examination and evaluation of a building. These methods aim to study the effectiveness of designed environments from human user perspective (Zimring et al. 1980, Bechtel et. al. 1987).

The outcome of the method can be a report defining what are the strengths and the weaknesses of a building. The results are usually repeatable, because the used method is systematic and adapts also to other cases. In addition to repeatability, the results are very useful especially in the building development. Development aspect is perceived by many stakeholders; including architect, engineers, tenants, owners and consultants. Mostly POE is targeted to occupants' point of view. This utilisation is only limited by the structure how POE is conducted.

History of POE dates back less than thirty years, when first case study of POE method was executed. Since that the concept has gained universal approbation and is nowadays frequently used. There are also many other abbreviations meaning same process: Building Evaluation (BE), Facility Performance Evaluation (FPE) and different types of customer satisfaction surveys. In connection with customer surveys certain aspects have to be taken into daylight. POEs are more than "customer surveys"; they are absorbed in the profound building essence. It is obvious but this systematic investigation and analysis of the structure and relationships between design objectives and occupants' experiences is taken into consideration in future development efforts.

Another way of looking are the verification purposes. We need to be sure that the intensions of the design have really become true. We need to determine whether the finished building actually meets the specified attributes. Therefore, post occupancy evaluation methods are needed (Ang 1996, Preiser 1996, Margulis 1996). As mentioned earlier, POEs are useful to everyone who comes into contact with a building. POE is a powerful diagnostic tool that allows people to learn about their past, mistakes and successes alike (Preiser 1988).

The purpose of tool is simple: it helps practitioners to avoid repetitive mistakes. First, it needs to have two sided opinions, both researchers and the target audience. Second, it improves buildings and procedures many ways like

- reduction of the design and maintenance costs
- increase of the customer satisfaction
- more comfort
- better performance
- increase of the attraction in the building
- solve problematical issues
- investment payback time modification.

1.6.1 Theory

Most significant attributes of POE are: i) it's a strategic tool that helps to understand critical parts ii) it is very flexible and adaptable to various circumstances iii) it can be implemented as a simple or complex manners. Approach for POE is adjustable, typically evaluations are case related including content and depth is allocated to attain required level. Preiser (1988) defined following basic forms of POE.

Indicative POEs are carried out by quick walk through evaluations. This involves structured interviews with key personnel, group meetings with end-users, as well as inspections which document building performance photographically or in written form.

Investigative POEs are more in-depth and utilize interviews and survey questionnaires, in addition to photography, video recordings and physical measurements.

Diagnostic POEs are focused, long-term and cross-sectional evaluation studies of such performance aspects as stair safety, orientation and way finding, lighting solution, privacy, overcrowding, etc.

1.6.2 Process

POEs are usable in different building types and buildings from various eras. It is applicable to new buildings or renovations. Ziemring et al. (1980) and Bachtel et al. (1987) stated that POEs are convertible in scale, resources, goals, methods, evaluator expertises, evaluator interests. Generally, most ot the evaluations have five principle phases in common which are (Zimring et al. 1980)

1. Entry and initial data collection
2. Designing the research goals (including choosing research designs and methods)
3. Collecting data
4. Analyzing data
5. Presenting information.

All-embracing POE has only a few boundaries but many advantages. The method can contain simple or complex case building. Time period is also convertible, depending of the evaluators, extent and type of information what is under investigation.

Methods that have been used in completing POE include interviews of building users, questionnaires, observation of environmental activity, checklists, and methods of recording the physical settings, such as energy consumption. Whether there is a variety of different methods in conducting POE, the fundamental purpose is assessing the building successes/strengths and failures/weaknesses from the standpoint of the occupants. Not to forget, POEs can be implemented when ever after construction. There are potential sources of errors present, as emphasised role of planner or excessive confidence on experts.

More detailed strategic process has also been presented by Chambers M. (2003) which has been adapted from Preisers' material. Basics are described with more detailed manners and fundamentals of five steps are divided to more extensive phases. Detailed strategic process is described below.

Planning the POE

1. *Reconnaissance and Feasibility*
   - To initiate the POE project
   - To establish realistic parameters regarding the client organisation's expectations of the evaluation
   - To determine the scope and cost of project activities
   - To obtain a contractual agreement against outsourcing
2. *Resource Planning*
   - To organise enforcing resources
   - To develop all level cooperation and support in the organisation.
3. *Research Planning*
   - To develop a research plan which ensures that appropriate and credible POE results are obtained
   - To establish performance criteria for the building
   - To identify appropriate data collection and analysis methods
   - To develop appropriate instruments
   - To allocate responsibility for specific research assignments and
   - To devise quality control procedures

Activities during the Planning the POE

1. Preliminary inspection of building to be evaluated
2. Determination of existing building documentation
3. Identification of significant building changes and repairs
4. Definition of project parameters
5. Development of work plan, schedule and budget
6. Formation of POE project team
7. Identification of archival resources on client organization documents
8. Inspection of building
9. Development of research instruments
10. Classification and development of performance criteria for the evaluation

Conducting the Field Research

1. Initiating the On-Site Data Collection Process

- To prepare the evaluation team and the (client) organization for on-site POE activities
- To coordinate the timing and location of POE activities
- To minimize disruption of routine functions of the organization.

2. Monitoring and Managing Data Collection Procedures

- To assure collection of appropriate and reliable data

3. Analyzing Data

- To analyze data
- To monitor data analysis activities in order to ensure reliable results
- To develop findings that are useful and insightful

Activities during the Conducting the Field Research

1. Building orientation for the POE team
2. Practice runs of data-collection procedures
3. Reliability check among observers concerning data collection

4. Preparation and dissemination of data-collection forms for distribution
5. Collection and collation of data recording sheets
6. Documentation of POE process
7. Review of reliability of raw data
8. Review of results of data analysis
9. Interpretation of data
10. Structuring of results

Applying the POE Results

1. Reporting Findings

- To report the findings and conclusions of the POE according to the organization' needs and expectations'
- To provide clear and accurate data that support the findings and recommendations

2. Recommending Actions

1. To make recommendations and stimulate action based on the findings and conclusions of the POE process

3. Reviewing Outcomes

2. To monitor the life-cycle implications of the recommendations

Activities during the Conducting the Field Research

1. Development of presentation formats
2. Organization of report contents and other presentations
3. Preparation of documentation
4. Formal review of findings by organization
5. Review of project findings and needs with (client) organization and building occupants
6. Analysis of alternative strategies
7. Prioritization of recommendations
8. Continued review and monitoring of implemented recommendations
9. Reports on results of the effects of changes to the evaluated buildings and subsequent buildings

1.6.3 POE Tools

POE investigations reveal many streams inside the building. There are many ways to integrate planning and POE process. There are possibilities to implement strategic planning (i.e. project management, scheduling, contracting etc), space management (i.e. space allocations, churn management etc), human factors (i.e. ergonomics, comfort etc), indoor climate (i.e. air quality, lightings etc.) and sustainability (energy consumption, recycling etc).

It is thought that having information about what contributes and detracts from occupant satisfaction, as well as overall building efficiency is useful in making a better quality building. POE has become successful in past decades, mostly in new buildings. Still there have been relatively little publications about renovated buildings, not to mention sustainable "green" buildings. This is potential spot to target POE investigations agreeing with the performance approach. POE has a significant contribution to the field. It offers basic data for different check list, requirements management and many other decision support tools and is in this context worth of its weight of gold.

According to Preiser (1996) a framework of POE with an emphasis on performance concept in buildings has been presented. It has four types of performance related aspects

- health/safety/security level of performance
- functionality/efficiency/workflow level of performance
- social/psychological/cultural level of performance, including aesthetic considerations

- process related aspects of building performance, e.g., work processes, management and operational processes

Whether areas are included in investigation is a case sensitive issue. Each case can exploit several POE tools. Lists of POE tools available have collected by Chambers M. (2003)

- visual inspection
- surveys
- interviews
- working observations
- maintenance records
- expert evaluations, testing, etc.
- check lists
- analysis tools
- digital photos
- as-built (record drawings)
- energy use records
- recording instruments.

POE in Usability Walk-through Case

Next, a case study utilising investigative POE method is presented. Case material was written by Nenonen et al. (2004). Case is located to Southwest Finland, particularly to growing area of Turku science park area in Kupittaa. Immediate surroundings involve three university buildings and the Turku polytechnic. Building itself is an old ceramic factory renovated for the use of ICT-companies. Interior of the building has been left exposed in the renovation giving the estate its unique feeling of combining modern technology with historical features.

The Old Mill has its own profile and identity which differs from the surroundings and manages to provide something unique for the companies. Slogans in www-pages describe: "From a ceramic factory to a technology centre". It includes a number of additional services alongside its functional and interesting office space. The building is equipped with latest data network connections, many meeting rooms and an auditorium. Sodexho manages restaurant services and Petrasol Business Centre oversees the running of reception area, switchboard, and as well as the building's Intranet.

Concerning space distribution, 84 % of the total floor space is leased for the tenants. The share of actual office space is 69 %. Overall, about 23 m^2 of office space is reserved per worker.
The focus in the case study was finding out how user information about the status of usability in Old Mill should be gathered. The case study used three ways to gather data

1. The questionnaire
2 .The usability walk through
3. The application of EcoProP software

The questionnaire was a telephone interview with simple answers concerning the environment. Basic structure of the questionnaire based on the classification of real estate made by Brand (1993) and applied by Blackstat (2001).

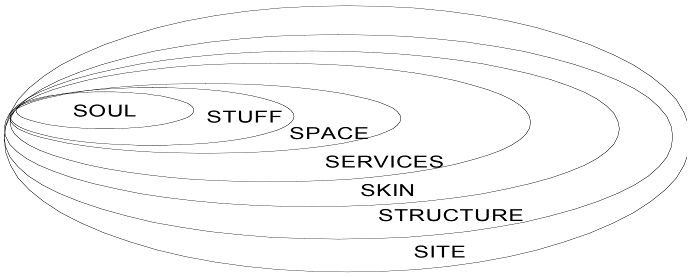


Figure 28: The seven S-model (Adopted from Brand (1993) and Blakstadt (2001)).

Brands model includes six S and Blakstadt (2001) added the seventh S, the Soul. In this setting the Soul represents the user and the source of data is users' experience. The definition of usability according to ISO 13407:1999 is: "effectiveness, efficiency and satisfaction with which a specified set of users can achieve a specified set of tasks in a particular environment". The questions were both asking if people were satisfied and are there enough easy to use services.

In walk through evaluation, the end users evaluated the focus area diagnosed as high or low usability (the diagnosis phase). The technique is suggested as a tool to evaluate the workplaces, identifies the gaps between the original design concepts and the current use, and provides a communication platform for different parties. The team for usability walk through included: an architect, service providers, facility manager, end user and usability researchers.

Participants were encouraged to reflect their views on the facilities to open questions. Topics were recorded. During the walk through, the participants observed the facilities and discussed about the causes and effects of space use. Participants speculated on following four milestones: entrance space, restaurant, meeting room and parking area.

The status of usability in Old Mill is quite high, but there were some improvable areas

- customer orientation in the car parking area (*serviceability*)
- 'smarter' (multiple) use of the entrance hall - focus on different options and communication amongst the users (*learnability*)
- efficient and rationalised restaurant logistics (*functionality*)
- better orientation and way finding to the meeting rooms (*functionality*).

Systematic requirements management software, EcoProP (Defined earlier in this report), is used in the usability case study by two ways

- to develop a hierarchy of performance requirements for usability and different performance levels for it in order to develop a usability profile
- to develop a dialogue and combine building hard data and user soft data.

Summary

The main issue was not measuring but investigating and improving the usability. **The diagnosis** phase investigates the weakest points in usability and the outcome of this phase is a general picture of the status of usability according the user's experience. *The questionnaire* can be used to gather quantitative and informative information. **The discussion** phase provides closer and in-depth investigation offering also the possibility to gather different points of views in defined target area with low usability. *The usability walk-through* produces qualitative data based on group interviews and observations. **The dialogue** phase is an interaction between the building technical data and usability data – the outcome is a usability profile, which is an illustration to be used in branding process as well as in ongoing improvement efforts. Exploitation of EcoProP was one of main objectives in the dialogue phase.

The 3 DI-analyse model is a way to find the solutions for workplace usability. The intention is to develop usability of workplaces in a way, which provides the concentrations to essential issues in an effective way. The question which needs consideration is whether the improvement process is applicable to all phases.
The summary of the results defined low and high usability attributes regarding site, structure, skin, services, space and stuff. Low usability was portrayed as lack of customer parking places, diminutive help and guidance signs, lunch time slow catering services, emptiness of entrance hall and complicated controls of lighting and air conditioning. High usability was defines such as nice imago, secure infrastructure and structural selections, functional security services, efficient helpdesk services, comfortable meeting rooms and wide range of offered ICT work possibilities.

Following learning points were find relevant:

- intangible character of brand is a relevant way to approach usability
- dissatisfaction management is a good starting point to investigate where the usability can be increased
- user experiences have an emotional background: this fact of subject is important to keep in mind during the gathering of the information
- results of the usability surveys have to be handled as a part of the process, not only as frozen facts and figures
- product domain, the task domain and the personal domain are important to be recognised as well as the user perspective or the structure in usability discussions

The case study concentrated purely to the common areas in the Old Mill. Individual workstations were left out in this phase. Future challenges in developing are the use of EcoProp for creating the usability profile as such but also in organisations with their own brand, with their own user requirements within the Old Mill and the science park area.

1.7 iBUILD

Today's markets need to react faster and faster to changing needs and wishes. In other industries individualization of demand is pushing production companies to new limits and innovations to comply changing needs of customers. Clients should have possibility to actually influence on the building process outcome. Traditional procedure of individual collaboration is carried out in the high end of the market. The larger part of the total housing market, the lower end, is restricted to standard designs. Two main concerns in current housing business, addressed with iBUILD, drive innovations described in this chapter

- individualization of demand: suppliers have to be more client-oriented (sometimes called 'consumer-driven')
- more customer centric companies: collaboration saves both cost and time and improved communication is seen as a key issue here.

1.7.1 Theory

Companies are improving building process efficiency and attention has been paid especially to data transfer characterized by following deficiencies: insufficient production information in designs, large share of data is fed into the systems multiple times, inadequate interoperability between applications, insufficient collaboration and data exchange. The current production process is not geared to address customer-specific demands without considerable increase of costs. Private customers in Europe don't want to make all construction detail decisions but they expect that they are able to specify e.g. layout, exterior design, or the quality level of facility.

Mass customization meets the requirements of increasingly heterogeneous markets by producing goods and services to match individual customer's needs with near mass production efficiency, using predefined and configurable parametric building components. Process provides also DS tools with selection information and feedback almost in real-time. Simultaneously communication between non-professional client and professional actor improves. Overalls, there is very strong social aspect existing: better wellbeing reduces stress and instability in neighbourhoods particularly in lower quality areas. Local authorities enable clients' individual decisions by defining when design complies local building local rules and regulations.

1.7.2 System structure

iBUILD is a concept to enable market driven product development in housing by modular intelligent parametric designs for houses. Designs can be adapted by clients to indicate their preferences and are at the same time optimized for the supplying industry, project logistics and building methods of a construction company to address mass-produced prices. Computer applications help the non-professional client in decisions and visualise consequences. The system streamline the building process through the generation of drawings, support in selection of building products from suppliers, to derive plans and schedules, to prepare procurement orders and production orders. The system is integrated and layered.

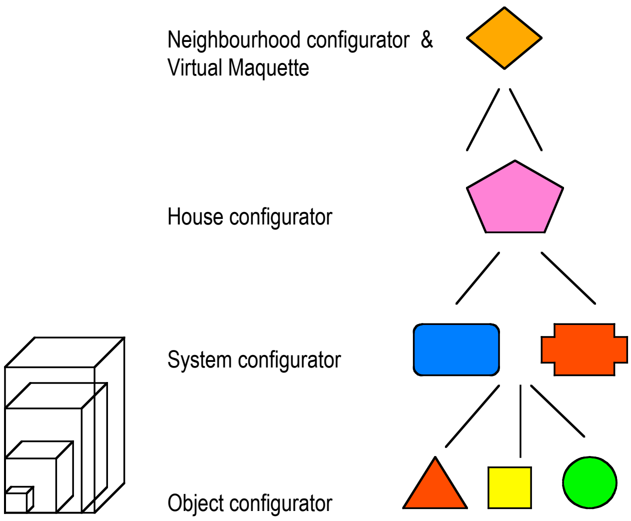


Figure 29: iBUILD levels of detail.

The first two detailed level layers are for professional users, such as project developers and designers preparing parametric reference designs. The latter ones are for non-professional users.

The first level, Object toolkits, specifies atomic building objects recognized by CAD (Computer Aided Design) and ERP (Enterprise Resources Planning) applications. Object has information of specification, production, procurement, logistics and visualization. Information is stored to object libraries structured according to international standards.

The second level, "System configurators", prepares parametric designs of more complex subsystems, such as window- and doorframes, partition walls and kitchens. CAD/CAM is possible through transparent information flows through participants.

The third level, "House configurators", is a combination of "system configurators". It perceives restrictions on (structural) safety, energy consumption, neighbourhood plan, building regulations, etc. It is connected to VR system and gives to client a possibility to walk through and furnish own designs and see cost consequences of selections.

The fourth level customised houses can be placed in a virtual maquette creating an actual "photo realistic" image of the development of a neighbourhood. Tools support selections and choices on economic, environmental and sustainable aspects.

The benefits of iBUILD address issues are: streamlined construction processes by more industrial building and focus on client needs for the same or even a lower price. Investigations have shown that few requirements influence the early decisions to select a specific house or house type. ICT tools translate the various parameters into feasible design decisions and propose several design solutions. The content of the system will of course be country (even company and project) specific but all the languages and models to describe the content implemented in the system are fully generic and not bound to any country. The system is built on open international standards of data transfer and interaction.

There are a number of main modules with three interface types:

- iBUILD engine. information storage and transformation services. International open standards such as Industry Foundation Classes (IFC) data format and XML based data transfer are used. Provides quick visualisations, transformations (XML languages), selections, export functions and web agent powered searches (W3C recommendations).
- The collection module for reference designs. Contains parametric objects and systems.
- 3D configurators is decision support tool that enables clients to decide on the possible variations and options, and that enables them to see the consequences of their decisions in real-time. Decisions can be viewed using modern VR and AR techniques.
- Performance checking can be implemented for: energy consumption, room sizes, comfort levels, acoustics, lighting, other services and regulations in real-time.
- The building process module provides an interface to production and realisation. The 3D specification model establishes both production and procurement orders.

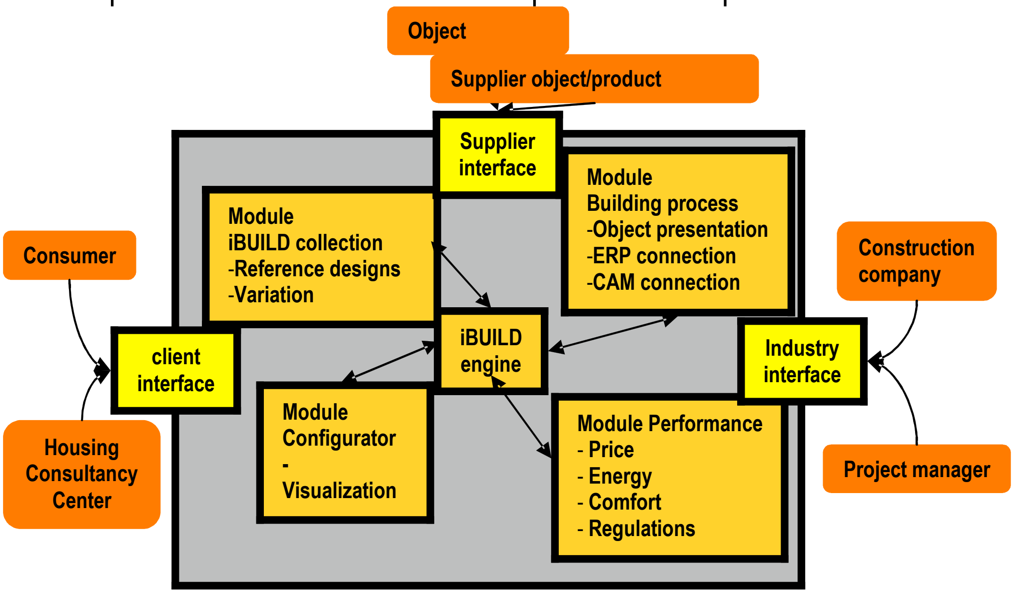


Figure 30: iBUILD architecture.

Web ontology provides domain knowledge. Semantic web developments in classifying the various objects, how they are specified and differ within a family of objects is used to denote semantic information. Building specific ontology is needed for meaningful information exchange and communication. Some information is already available based on the work on Industry Foundation Classes (IFC), aecXML (architecture, engineering, construction XML), bcXML (building and construction XML), which address building and construction semantics using XML.

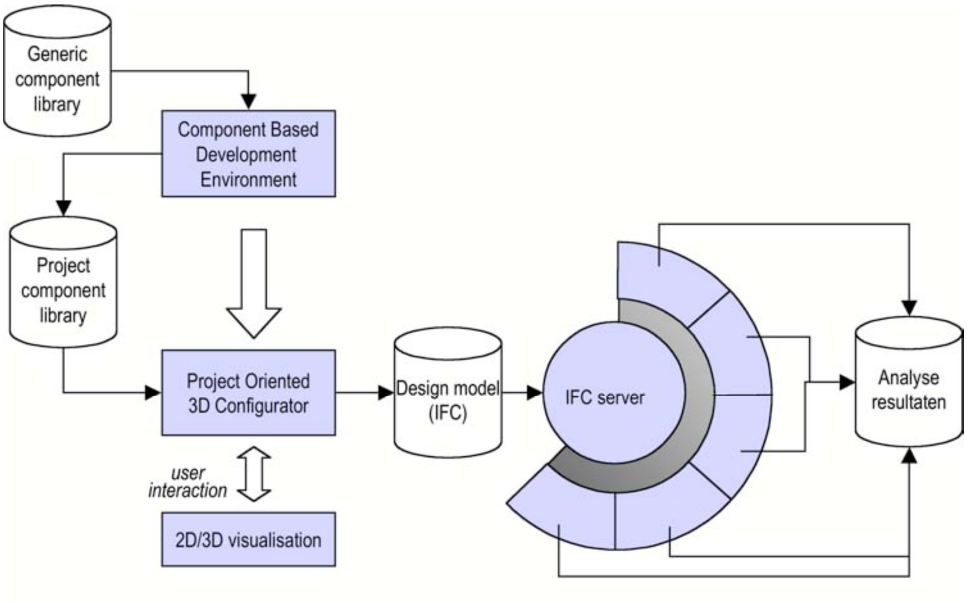


Figure 31: ICT architecture.

Components are a software model of specific building and construction concepts, such as wall, wall system. Semantics and mutual relations have to be specified independently in ontology. The Semantic Web approach is also used to develop exchange mechanisms with all stakeholders without having to agree upon a detailed exchange interface. Semantic web technology enables the implementation of 'ad-hoc' information exchange.

End-user interaction

New house inhabitant interaction builds on the presence of advanced Virtual Reality (VR) technology. Users are able to visit their newly designed house 3D VR model in internet. System visualizes various possibilities and supports the parameter selection and decisions making. Real-time cost effects help to establish priorities in requirements. It is supported by early 3D visualization, which results in a house design with an optimal (subjective) user satisfaction. Current Virtual Reality applications do not need powerful computers with high-end graphic cards. The average notebook available today in supermarkets is sufficient. For Augmented Reality (AR) special devices may be necessary, such as shutter glasses.

Variations of the house to be configured include:

- Budget range: comfort level and floor number determine the plot the house is built on.
- Size of the floor plan: user interface using sliders sets the basic lay-out of the house.
- Stairs location selection: user has sliders to determine the limited staircase location.
- The results of global house design in 3D. System enables also the adjacent house.

Summary

The concept presented here addresses using modern ICT in conjunction with a transparent, open process between all stakeholders. Mass-customization enables houses on consumer request and combined to ICT it leads to customer satisfaction.

Prospective new house owners have a possibility to make set of choices and tailor parameters that will facilitate their selection process. Tools translate the various housing client parameters into feasible design decisions and propose several design solutions. The resulting information is used throughout the down-stream processes, controlling downstream ordering, production and assembly processes through ICT using international standards. The concept helps to configure private homes and establishes fully compliant housing to needs and produces unique solution for serial production prices. Real-time cost information and 3D VR model help to establish priorities in requirements to reach an optimal and subjective user satisfaction. Producible and sufficiently detailed designs are integrated to logistics with all suppliers.

Pilot projects are used to investigate actual performance of the concept and to assist in result dissemination. Pilots are addressed to develop following subsystems: sales process support for fast responds to quotation requests, functional house configurator for design and complete 3D kitchen configurator.

Figure 32: VR Model of the house and adjacent house.

Testing the Tools

CHAPTER 2

2 Testing the Tools

Selected Decision Support Tools (DST) for Performance Based Building (PBB) were tested by VTT and the University of Reading in two workshops: first at Delft in October 2004, and then at Porto in November 2004. They cover different phases of the building process life cycle emphasising at the early stages, where decisions can really have an impact on the end product performance at reasonable cost consequences.

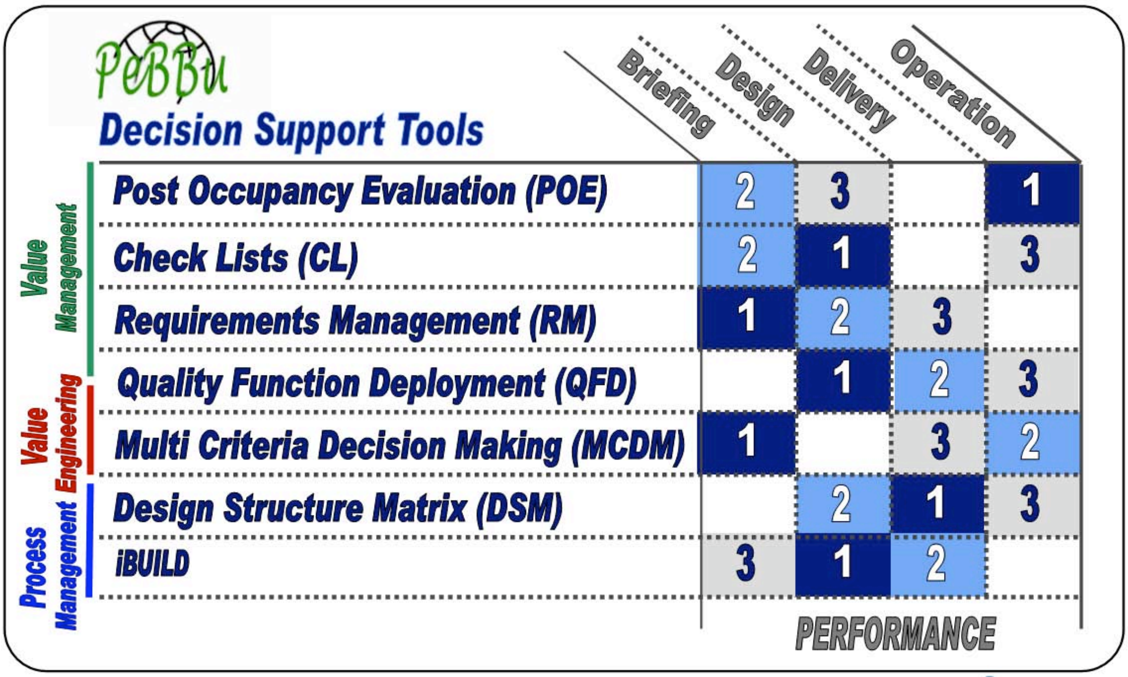


Figure 33: Selected PeBBu Decision Support Tools and their primary applicability.

2.1.1 First Trial at Delft

The overall objective of the DST task was to collect and validate a set of applicable tools that add value in decision making in different stages of performance based building for different actors. The tools should preferably be interoperable so that one might start with one tool and continue with another as shown in the following illustration.

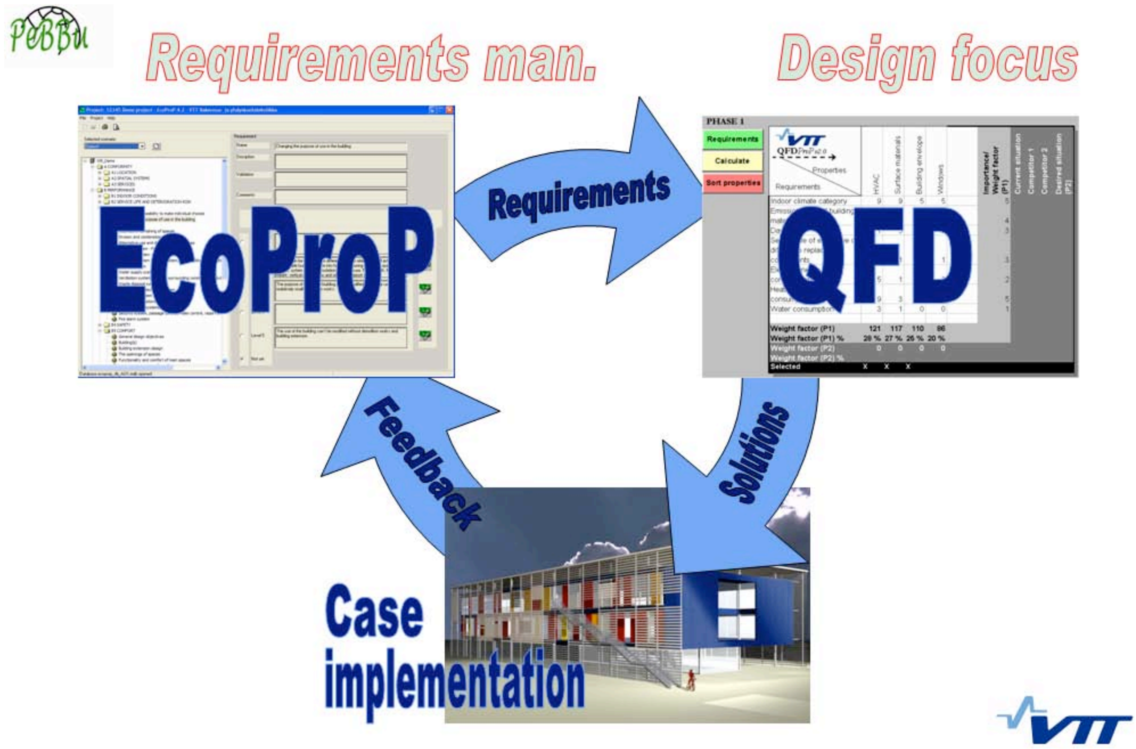


Figure 34: An example of integrated value management tools.

The first trial was conducted in Delft in October using a single family house that has been built in Kotka in Finland (Loiste) as a test case. It highlighted innovative energy efficient steel frame solutions of high comfort. The test focused on managing the indoor conditions. The second test was arranged in Porto in November using an industrial, adaptable and durable office building case that had been designed in the Netherlands (IFD Building).

2.1.1.1 Case: Loiste in Kotka, Finland

Loiste is a steel frame single family house built for the Annual national housing fair in Finland in 2002 in Kotka. The building has already been built two years ago and documented for IEA task 28. Therefore, it offered extensive documentation from design objectives to technical requirements and other valuable information. The original performance requirements of Loiste case were set using EcoProP for systematic requirements management.

Following case information is adopted from IEA Task 28 case report (IEA 2004). The house is a modern, light steel framed house that combines different construction systems and materials in the facades and interior. The facades are partly rendered and partly covered with wood panelling. Parquet floors, wooden steps, soapstone and ceramic tiles bring colour to the interior. The floor area of the two-storey light steel framed building is 193 m^2, comprised of four rooms, kitchen and a dining area, sauna facilities, and a multifunctional area. The house has also a garage, a carport and an outdoor storage. The house is standing on a slope towards the sea. Two foundation systems were used. Part of the building has a slab-on-ground foundation. On the slope drill steel pole foundation was used to avoid quarrying and ground work.

Figure 35: Marketing material from Loiste in Kotka Housing Fair, Finland (IEA 2004).

Loiste is an example of a marketable energy efficient steel building. The aim of the project was to design and built a single-family house that responds to the user requirements, and at the same time fulfils the high performance requirements set for the building. The aim was to demonstrate the user advantages of energy-efficient low environmental pressure housing. The aim of the project was to design and construct a large single family house, and to monitor and demonstrate the building to the public, construction companies, and other important clients. The broad aim of the whole demonstration project was that the demonstrated system could be adapted to commercial production by interested companies.

Loiste's structures incorporate modern steel structures in many ways. A new drill pole steel foundation with a new base floor design reduces the need for quarrying at the building site. Large prefabricated load-bearing element walls with factory installed base coat render reduce the delivery cycle. A steel balcony with wooden floor and latticework facing the sea increase living comfort. Energy efficiency of the house is improved with a steel roof integrated new generation Rannila Solar Eco solar collector. The energy efficiency of the building is based on good thermal insulation. The heat loss through the steel framed wall is considerably reduced.

The house is connected to local district heating grid for space heating and hot water heating. Heat distribution system is floor heating with room based temperature control. A fire place in the living room can be used both for comfort and additional heating device. Mechanical ventilation system with heat recovery is integrated to solar air collector. The reference year values in target setting were: space heating 120 kWh/m^2 and water heating 21 kWh/m^2. After year and half energy consumption monitoring the results indicated following: space heating 47 kWh/m^2, water heating 31 kWh/m^2 and electricity 22 kWh/m^2.

Testing the Tools

EcoProP software was used to collection of performance requirements. Focus areas taken to baseline of requirements profile were:

- Indoor conditions
  Indoor climate (FISIAQ classification)
  Acoustics (noise etc.)
  Illumination
  Vibration
- Service life and deterioration risk (Equipment and systems etc.)
- Briefing
  Briefing
  Business
  Image and brand
- Energy consumption (LCC and LCA calculations)
- Raw materials (water consumption)

Other topics considered valuable were:

- Process issues
  Construction
  Quality assurance
- Location
  Transportation (Light transport, traffic around etc.)
- Spatial systems (spaces etc.)
- Accessibility (handicapped, visually and hearing impaired etc.)

During the requirement setting process important comments were given from workshop members and added also to requirements model. Strength of EcoProP is that it gives hierarchical approach to understanding multi dimensional nature of requirements given by user and authorities.

EcoProP provides advanced features for creating reports, it's supported to generate reports for certain participants or thematic groups into web page or word document format. In Loiste case the report was also generated after the meeting.

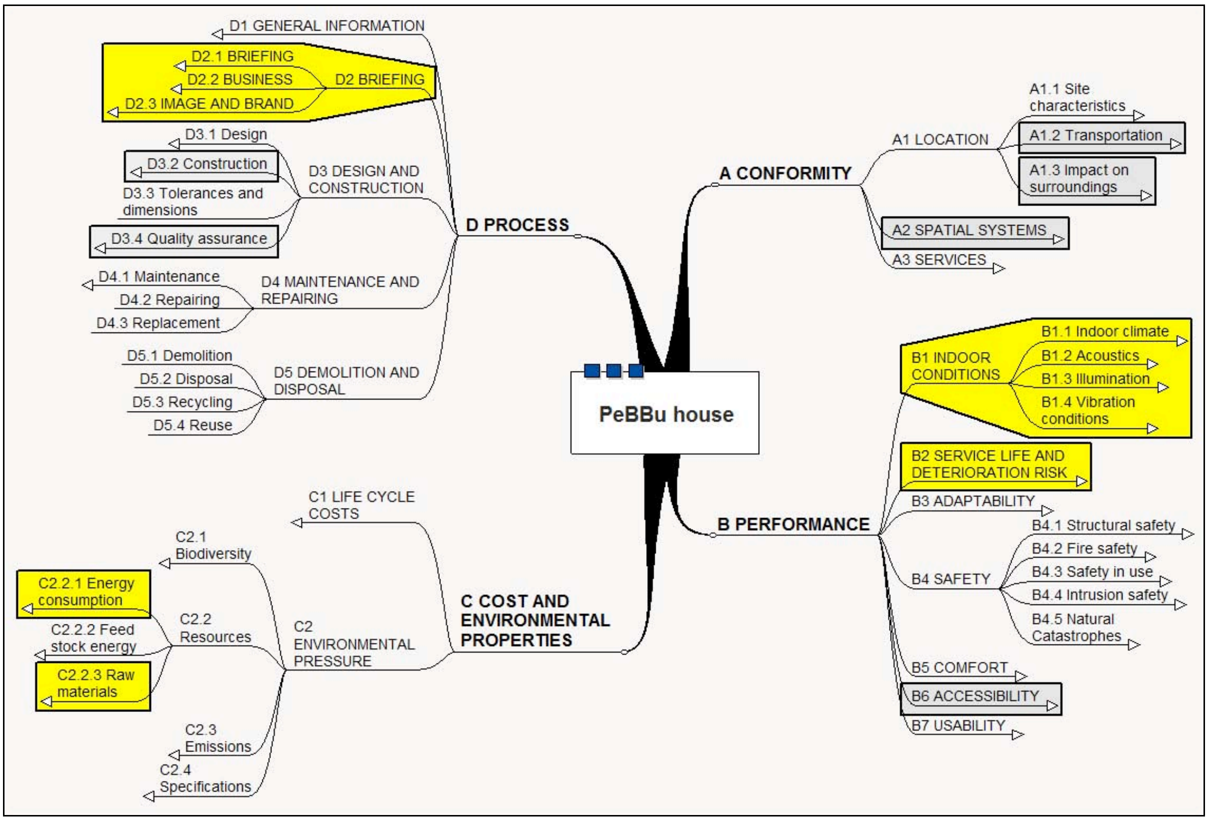


Figure 36: Focus areas from VTTProP® classification considered in Loiste case; yellow indicates most important targets and grey supporting matters.

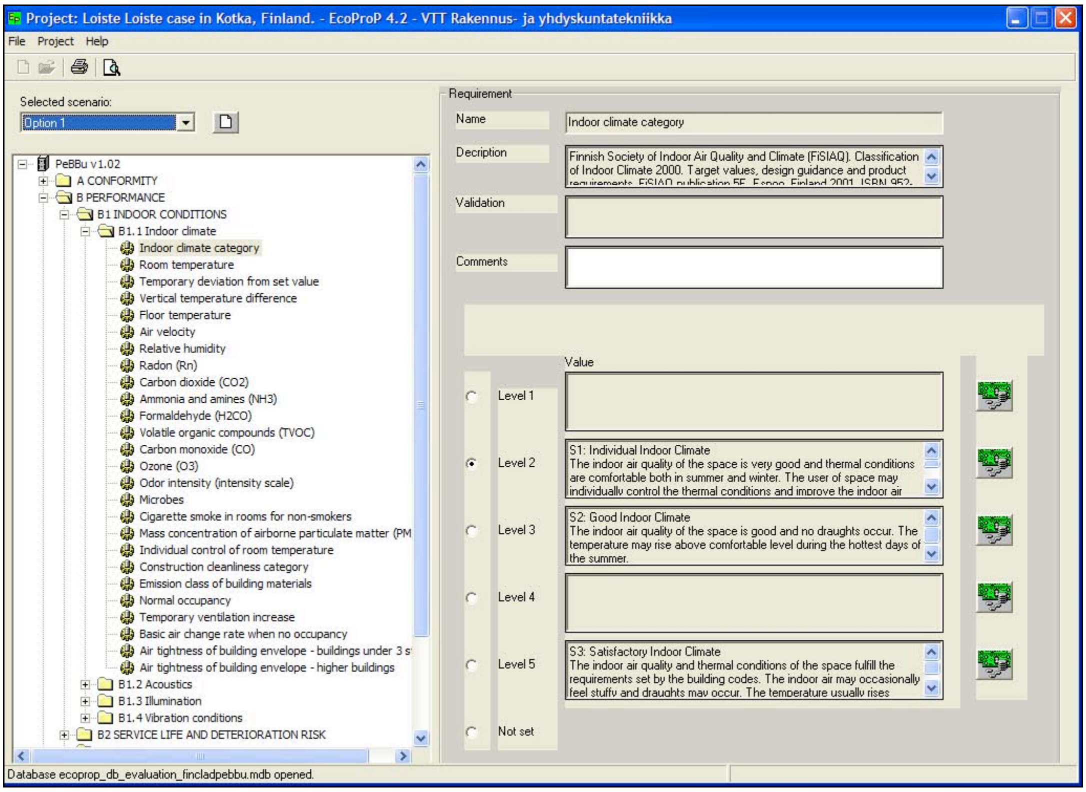
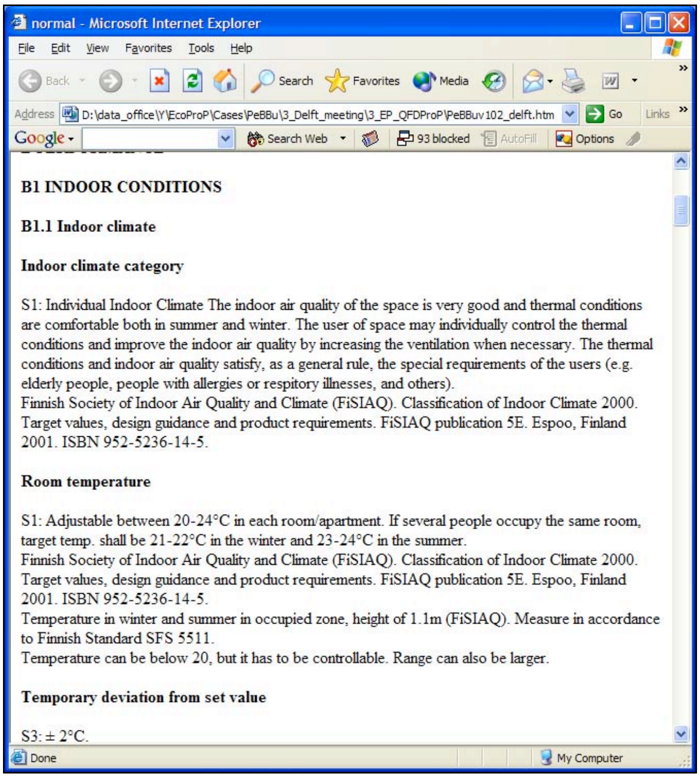


Figure 37: Setting requirements in the Loiste case for indoor climate in EcoProP software.



normal - Microsoft Internet Explorer

B1 INDOOR CONDITIONS

B1.1 Indoor climate

Indoor climate category

S1: Individual Indoor Climate The indoor air quality of the space is very good and thermal conditions are comfortable both in summer and winter. The user of space may individually control the thermal conditions and improve the indoor air quality by increasing the ventilation when necessary. The thermal conditions and indoor air quality satisfy, as a general rule, the special requirements of the users (e.g. elderly people, people with allergies or respitory illnesses, and others).
Finnish Society of Indoor Air Quality and Climate (FiSIAQ). Classification of Indoor Climate 2000. Target values, design guidance and product requirements. FiSIAQ publication 5E. Espoo, Finland 2001. ISBN 952-5236-14-5.

Room temperature

S1: Adjustable between 20-24°C in each room/apartment. If several people occupy the same room, target temp. shall be 21-22°C in the winter and 23-24°C in the summer.
Finnish Society of Indoor Air Quality and Climate (FiSIAQ). Classification of Indoor Climate 2000. Target values, design guidance and product requirements. FiSIAQ publication 5E. Espoo, Finland 2001. ISBN 952-5236-14-5.
Temperature in winter and summer in occupied zone, height of 1.1m (FiSIAQ). Measure in accordance to Finnish Standard SFS 5511.
Temperature can be below 20, but it has to be controllable. Range can also be larger.

Temporary deviation from set value

S3: ± 2°C.

Figure 38: A fragment of report from requirements set for the Loiste case in EcoProP software.

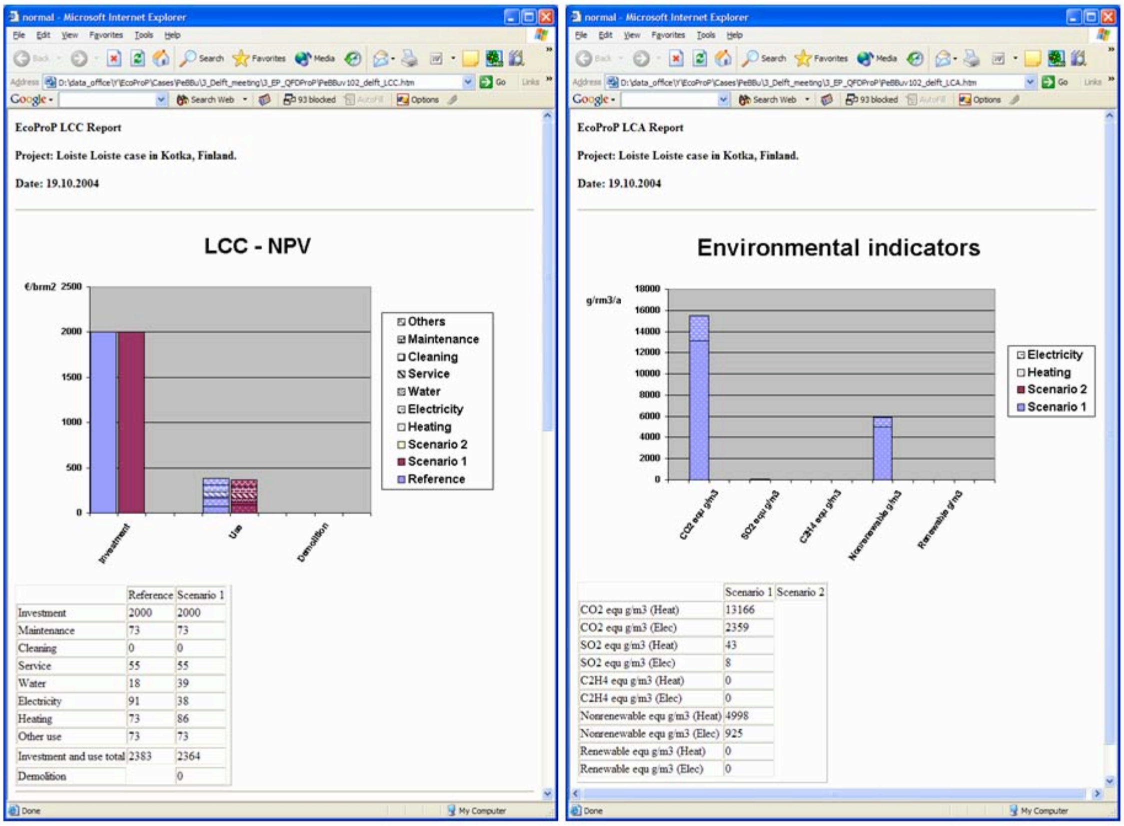


Figure 39: Life cycle cost (LCC) and life cycle assessment (LCA) calculations from requirements set for the Loiste case in EcoProP software.

2.1.2 The Second Series of Trials at Porto

The first DST workshop validated the test approach with a relatively simple housing case. An office case was prepared for the second workshop taking in Porto on 17th and 19th November in 2004. The workshop gathered all PeBBu domains together and DSTools were presented in all of them, using slightly different approach in each domain, trying to obtain as rich feedback as possible.

The DST agenda in PeBBu Domains was as follows

Domain 1: "Life Performance of Construction Materials and Components"
- DSToolkit presentation (Requirements Management, QFD)
- CRISP presentation

Domain 2: "Indoor Environment"
- DSToolkit presentation (Check Lists)
- EcoProP demonstration
- Reading QFD demonstration
- Pilot case presentation

Domain 3: "Design of Buildings"
- DSToolkit presentation (Requirements Management, QFD, iBUILD)
- EcoProP and VTT QFD testing
- Pilot case presentation and design

Domain 6: "Legal and Procurement Practices"
- DSToolkit presentation (iBUILD, DSM)
- DSM demonstration

Domain 7: "Regulations"
- DSToolkit presentation
- Reading QFD demonstration

Domain 8: "Innovation"
- Pilot case presentation
- DSToolkit presentation
- HIPRE and DSM discussion.

2.1.2.1 *Case: IFD Building, Netherlands*

The principle in IFD building development originates from three letters: I standing for industrial meaning development of solutions of high manufacturability and assemblability, F indicating high flexibility and adaptability and D expressing durability. Architecturally building is impressive and it supports multiple layout solution inside the office floors. Certain parts of the building are fixed while more flexibility is accepted in certain predefined areas. IFD building is a design concept from the Netherlands, there are no existing buildings following the concept. Therefore there isn't so much information handling design objectives of IFD building compared to previously defined Loiste case.

The leading ideas for IFD building development were

- High adaptability
- Good indoor conditions
- Low environmental pressure
- Optimised running costs and value
- Representing corporate brand: serving image
- Innovative design and technical solutions.

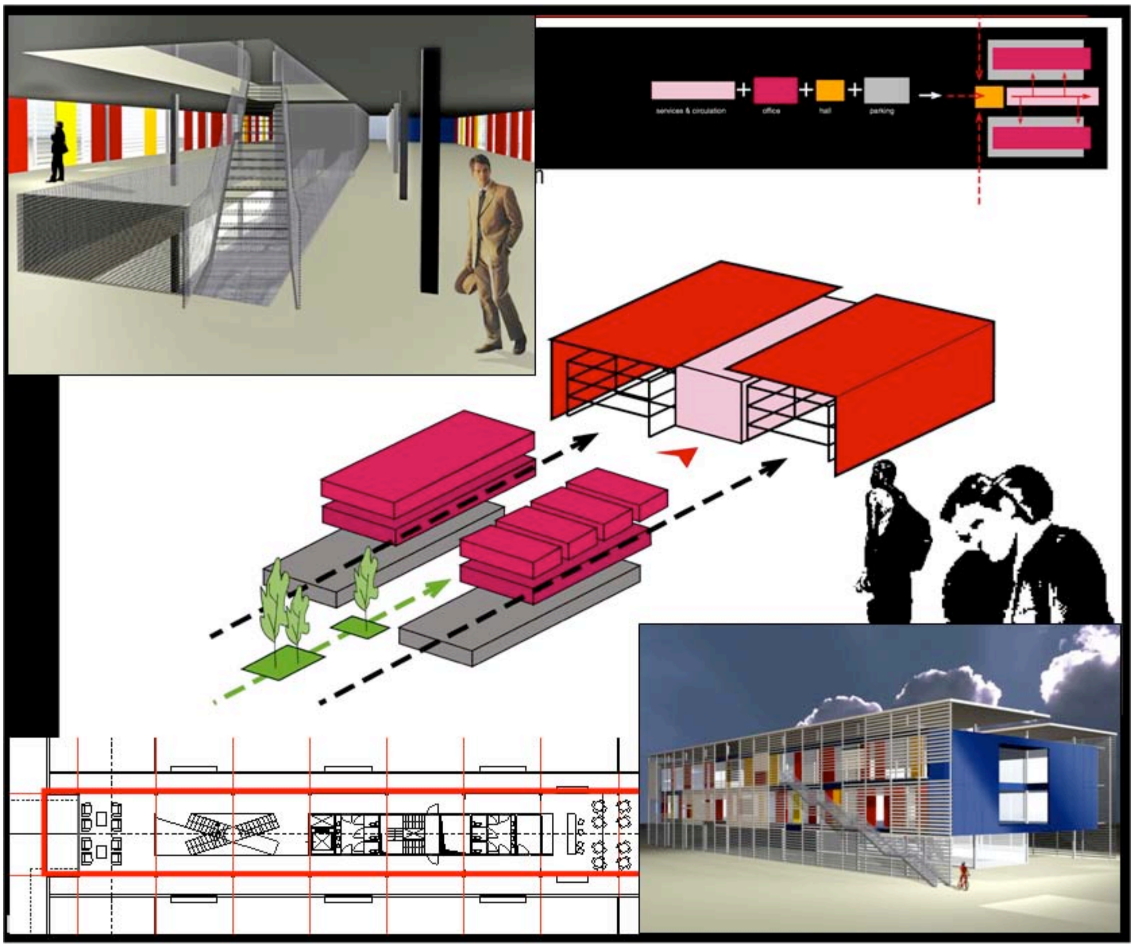


Figure 40: IFD Building.

Possibility of exploiting case implementation and DST tools was offered to each domain, it was up to the leader how much time and effort was provided to PeBBu DST tools task. The leader of Domain 3, Mr. Dik Spekkink (Spekkink C&R), exploited the most effectively the possibility of having live test with IFD building. Actually the IFD building case was provided for PeBBu use by Mr. Spekkink. The case was still rather large compared to time available but regardless shortage of time the results attained were astonishing. VTT ProP® classification was used to collection of performance requirements.

Focus areas taken to baseline of requirements profile were:

- Spatial systems
- Adaptability
- Comfort
- Accessibility
- Usability
- Briefing in the process
- Environmental pressure (containing energy considerations and raw materials).

Other topics considered:

- Location
- Service life and deterioration risk
- Safety.

In general, the focus areas of VTT ProP® are structured to a mind map where yellow indicates focus areas and grey means interesting topics.

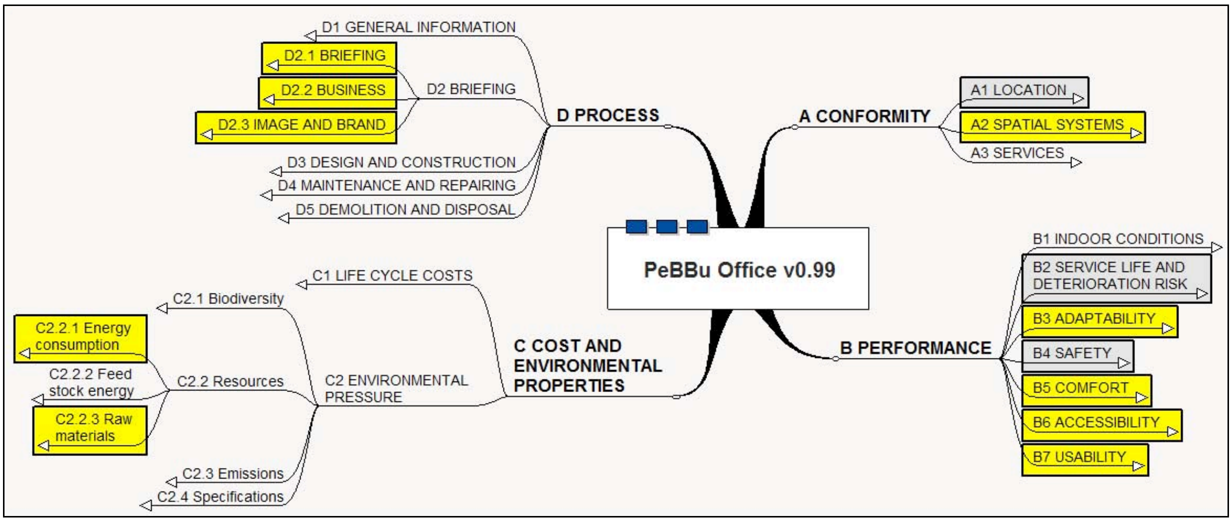


Figure 41: Focus areas from VTT ProP® classification considered in IFD building case; yellow indicates most important targets and grey supporting matters.

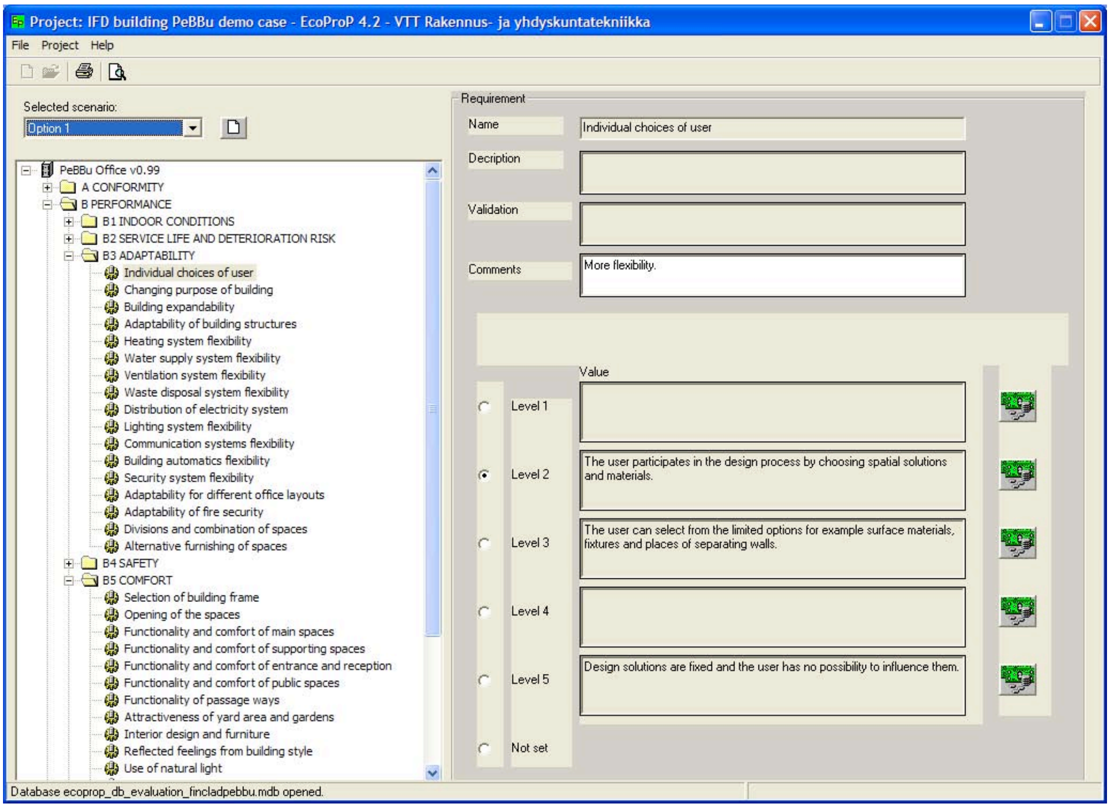
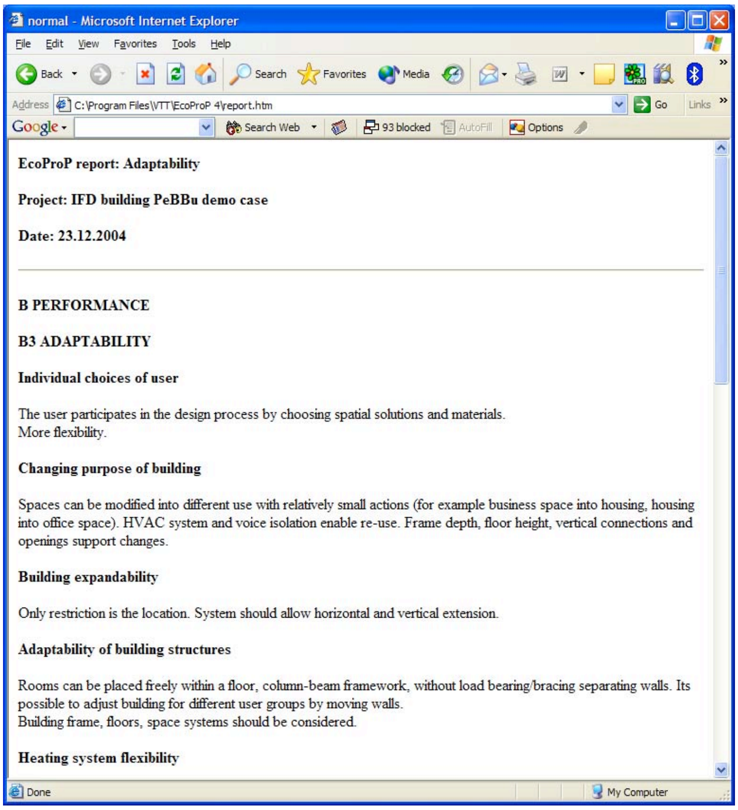


Figure 42: Setting requirements in IFD Building case for adaptability in EcoProP software.



EcoProP report: Adaptability

Project: IFD building PeBBu demo case

Date: 23.12.2004

B PERFORMANCE

B3 ADAPTABILITY

Individual choices of user

The user participates in the design process by choosing spatial solutions and materials.
More flexibility.

Changing purpose of building

Spaces can be modified into different use with relatively small actions (for example business space into housing, housing into office space). HVAC system and voice isolation enable re-use. Frame depth, floor height, vertical connections and openings support changes.

Building expandability

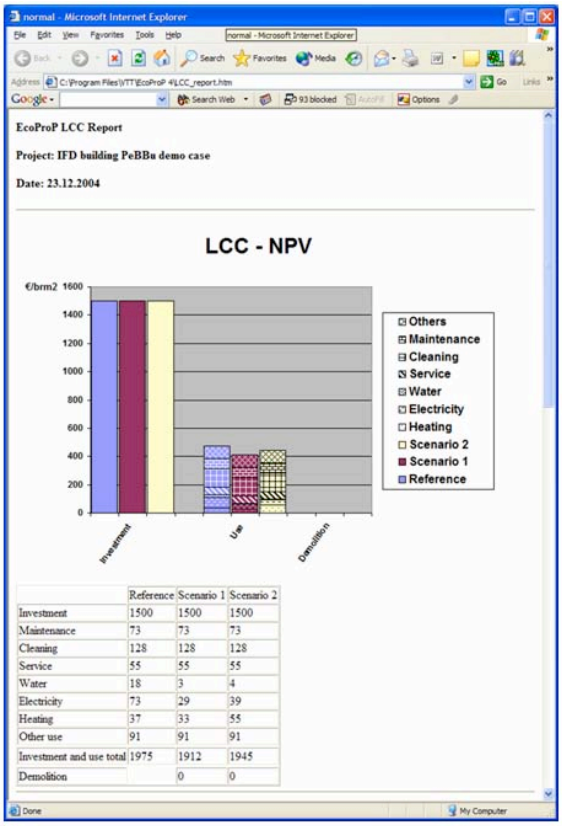
Only restriction is the location. System should allow horizontal and vertical extension.

Adaptability of building structures

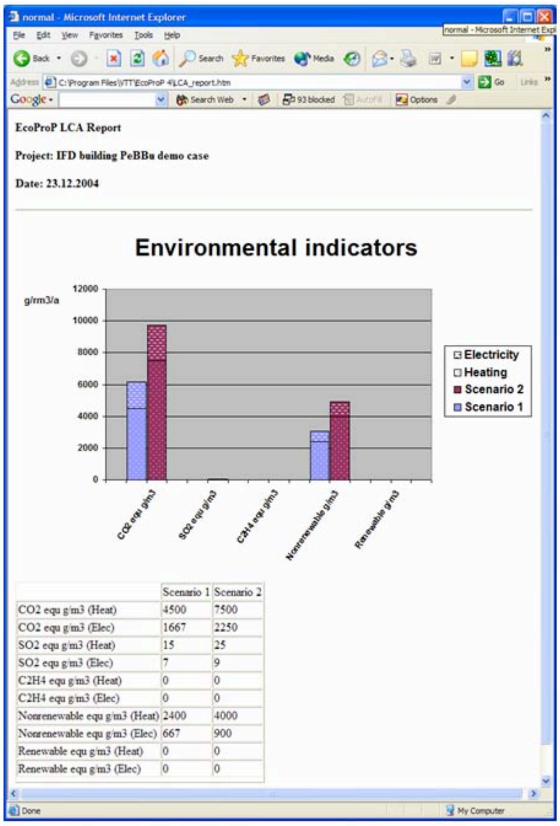
Rooms can be placed freely within a floor, column-beam framework, without load bearing/bracing separating walls. Its possible to adjust building for different user groups by moving walls.
Building frame, floors, space systems should be considered.

Heating system flexibility

Figure 43: A fragment of report from requirements set for IFD building case in EcoProP software.



	Reference	Scenario 1	Scenario 2
Investment	1500	1500	1500
Maintenance	73	73	73
Cleaning	128	128	128
Service	55	55	55
Water	18	3	4
Electricity	73	29	39
Heating	37	33	55
Other use	91	91	91
Investment and use total	1975	1912	1945
Demolition		0	0



	Scenario 1	Scenario 2
CO2 equ g/m3 (Heat)	4500	7500
CO2 equ g/m3 (Elec)	1667	2250
SO2 equ g/m3 (Heat)	15	25
SO2 equ g/m3 (Elec)	7	9
C2H4 equ g/m3 (Heat)	0	0
C2H4 equ g/m3 (Elec)	0	0
Nonrenewable equ g/m3 (Heat)	2400	4000
Nonrenewable equ g/m3 (Elec)	667	900
Renewable equ g/m3 (Heat)	0	0
Renewable equ g/m3 (Elec)	0	0

Figure 44: Life cycle cost (LCC) and life cycle assessment (LCA) calculations from requirements set for the IFD building case in EcoProP software.

Amongst the participants many countries and nationalities were represented. This was also noticed in the ranking of design objectives. The results indicate that the HVAC system has even more significance in the office building than it has in one family house case examined as a first test case. TO sum up the results it was clearly noticed that systematic procedures are needed and therefore QFD is strong addition to tools used in project meetings. QFD offers systematic approach to the ranking of complex design objectives. It's up to the participants how well its opportunities are utilised in project level.

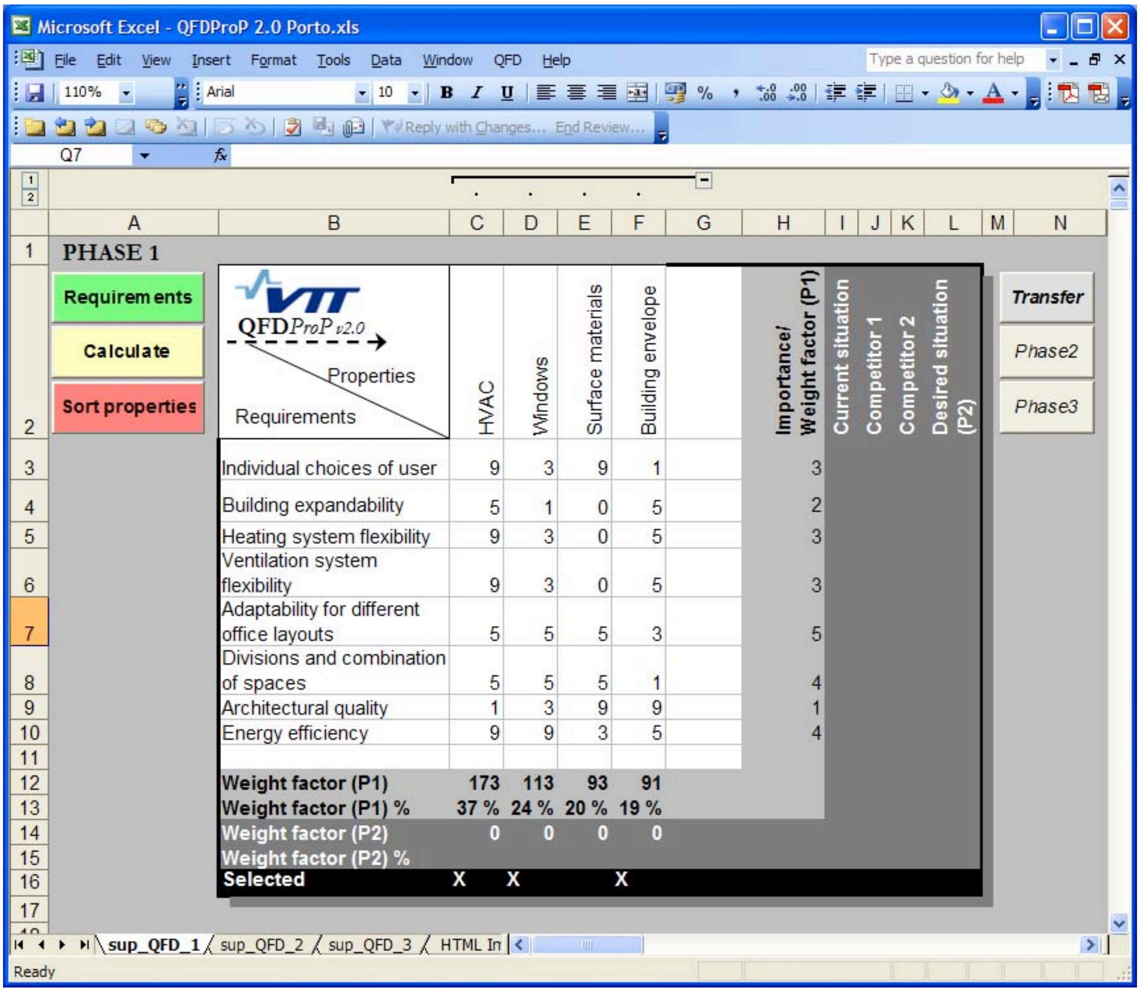


Figure 45: QFD ProP tool used to prioritising design objectives in the IFD building case.

The workshops gave valuable and important feedback on possibilities and outlined exploitation potential of the proposed DSTools. First test was carried out with simple one family house and it helped to structure basis for larger development effort in Porto November 2004.

Recommendations for Future Research

CHAPTER 3

3 Recommendations for Future Research

One of the starting points for drawing recommendations was the PBB Framework that was defined in PeBBu Domain 5 Organisation and management that is presented here in a slightly revised format based on experiences drawn in valuable tool tests.

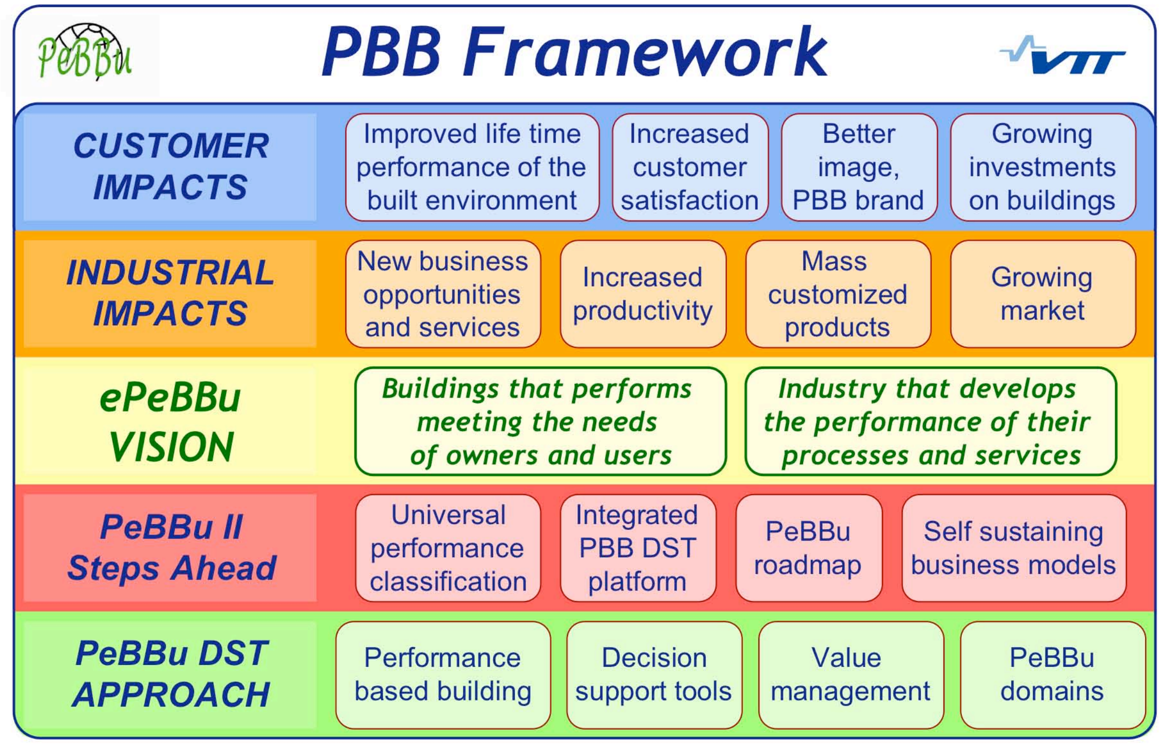


Figure 46: PBB Framework.

The recommendations are structured in five main categories and presented more in detail after this summary

1 International framework and universal performance classification

"a PBB Master list 2006"

2 Integrated platform with interoperable applications

"ePeBBu platform and PeBBu compatible tools" (PeBBu II)

3 Value models, incentives and constraints

"PBB Roadmap"

4 Value adding whole life services

"Self sustaining PBB business models"

5 Information dissemination, regulations and education.

3.1 International Framework and Universal Performance Classification

Problem: *No common means of true communication on performance properties exist.*
Performance based building needs a common vocabulary and a logical framework where different performance criteria can be referred to. A millennium version of a new CIB Master list could structure the high level criteria like the work was started in the CIB Compendium. The low level characteristics that may be material or technical solution dependent should be left open. A widely accepted generic performance framework would increase interoperability of tools and accelerate the diffusion of implementation.

Recommendation 1: Internationally accepted performance based building classification: a "PBB Master list 2006" (succeeding the CIB Master list 1964, 1972, 1983 and 1993 editions).

3.2 Integrated Platform with Interoperable Tools

Problem: *The support of performance management is scattered and number of isolated applications are unsystematically applied for sub-optimising individual solutions.*
Recently, the open international standards for building design information exchange have become more robust and more widely used. In particular, the International Alliance for Interoperability (IAI) has continuously carried out development and support work for Industry Foundation Classes (IFC) open information exchange specification. It is evident that product model technology has developed to a level where it can enable the attachment of data from various phases to it, such as requirements management.
This increases interoperability but authors highlight that many questions need answers. There has been debate going on concerning the structure of product models. Some argue that in the future there are various product models that are transferred in common data formats. Others are bringing forth Building Information Model (BIM): a large model combining together various models from different project phases. If BIMs are the future direction, they also promote way towards wider exploitation of product model technology. This shift is intended to motivate developers towards consumer driven process.

Recommendation 2: a "PeBBu II" should be activated focusing on "ePeBBu Platform" and "PeBBu compatible applications" with pan-European true experts on board.

3.3 Value Models, Incentives and Constraints

Problem: *Despite of the potential considerable benefits of PBB widely shared by researchers over the past decades very little, if any, change can still be observed in everyday practice.*
The reasons preventing the change must be identified and a credible path of progress with risk assessment is needed. A Roadmap describing the vision (or future scenarios) and needed action plan with relevant steps would show the way forward. Relevant landing points and indicators measuring the state together with listed incentives and barriers would complete the picture. Success stories (from outside or inside) or good practices could facilitate the implementation.

Recommendation 3: A cross-disciplinary study a "PBB Roadmap" objectively assessing various future scenarios could provide a discussion basis bridging various professions and disciplines.

3.4 Value Adding Whole Life Services

Problem: *It is still a mystery "current supply" could be transformed to meet "future demand".*
The industrial implementation of the PBB Roadmap needs methodological competence of forming value networks, establishing win-win-win rules and adopting customer oriented life cycle services. If the business models remain questionable no progress can be achieved.

Recommendation 4: Self sustaining profitable business models are needed to breed customer oriented networked life cycle services.

3.5 Information Dissemination, Regulations and Education

Problem: *People are lacking information and knowledge - it is a challenge to encourage innovation and development through regulations.*

Accessibility of information must be ensured. Value forming in the process enabling learning must be supported.

Recommendation 5: The development needs to be encouraged and assured at all levels.

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Annexes

Annexes

Annex 1: Experts Contributing to the DST Task

PBB Experts contributing to the Decision Support Tools Generic Task					
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