A MODEL-BASED DESIGN APPROACH WITH THE FOCUS ON ENERGY

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ABSTRACT

The purpose of the research is to investigate how a model-based design approach can facilitate the decision-making process in the early design phase. The construction client is in a key position to affect the outcome of a construction project by proper decision making during the design. Different design options can rapidly be analysed to assist the client in making informed decisions in the early design phase. The research approach is based on a theoretical framework for a model based design, decision-making methods and the case of a property in Finland in the early design phase with focus on energy performance. The result of this study is to provide guidelines on how a model-based design process in the early design phase can help decision-makers influence the energy performance of a building. The framework is believed to be generally applicable for decision-making in the design process.

1. INTRODUCTION

The building stock in Europe accounts for over 40% of the final energy consumption in the European Union (ENERDATA, 2003). Since, roughly 50% of the energy is based on fossil fuels the building sector also contributes substantially to the green house gas emissions.

Today, minimizing the investment cost is in focus for new buildings. However, the focus on production cost do not improve the service life performance (Öberg, 2005). Wise initial investments can decrease the total LCC (life cycle cost) for a building significantly. It is particularly important to show the relation between design choices and the resulting life cycle cost such as energy, maintenance and operation cost (Kotaji et al., 2003). An office building will cost about three times its initial investment cost, to operate and maintain, over a 25 year period (Flanagan and Jewell, 2005).

Therefore, a model based approach for life cycle design could be a tool for construction client and the design team to considerate and simulate all sustainable aspects of a building in the early design stage.

2. THEORY

2.1 Life cycle design aspects

An ideal sustainable design process has to include the life cycle design perspective where all solutions are optimised for the entire design service life of the building (Sarja, 2002). However, to improve the service life performance for a building several aspects need to be included in the early stages of the design. Sarja (2002) introduced four main aspects in his integrated life cycle design approach human conditions, financial cost, culture and ecology.

Outgoing from these main aspects, the most dominant aspect with regards to cost and environmental issues is the operating energy. Junnila (2004) shows in his study that the operating electricity causes most of the environmental impact during the life cycle of office buildings, also the operating heat and maintenance have significant impact on the environment. The statistic from the Swedish construction industry (2007) shows that one
of the major components of the life cycle cost during the operating time of a building is the energy.

![Diagram of integrated life cycle design](image)

Figure 1. Main aspects of integrated life cycle design (adapted from Sarja, 2002).

By optimising the design parameters such as building shape, the building envelope and orientation the heat consumption can be reduced up to 80% (Feist et al., 2005). According to Clarke (2001), energy simulations for buildings result in a cheaper, better and quicker design process, the outcomes will better match society’s aspirations for sustainable practices and environmental protections in particular with regards to the global warming.

### 2.2 Building Information Modelling

Building Information Modelling (BIM) is the process of creating object-oriented and parametric 3D CAD models. The verb BIM describes the process to create, store and use the noun BIM (Building Information Model). The noun BIM is a static representation of a building that contains multidisciplinary data that defines the building from the point of view of more than one discipline.

BIM applications generally operate on shared databases which enable them to capture, manage, and present data in an appropriate although coordinated way for each discipline. Such downstream applications start with capturing and managing the required information, and present that information back in appropriate way, and thus making it available for use and reuse during the project (Ibrahim and Krawczyk, 2003). Laiserin (2007) defines BIM as a process to support communication (sharing data), collaboration (acting on shared data), simulation (using data for prediction), and optimisation (using feedback to improve design, documentation and delivery). This definition makes no reference to any software at all, but software can automate and improve that process.

Virtual Design and Construction, VDC, is another acronym used to describe the model-based technology and working methods (Kunz and Fisher, 2008). According to Kunz and Fisher (2008) three levels of implementation of VDC methods in the building sector can be recognized:

- **Visualisation**: 3D models are routinely created and used to predict performance metrics. Especially, gains in clarification of project objectives for stakeholders and resolving of coordination issues between different design disciplines can justify the relative inexpensive investments made in the project.

- **Integration**: projects develop computer based methods to exchange data among different modelling and analysis application either using standard formats such as IFC (International Foundation Classes) or propriety formats. For integration to work well vendors need to agree on exchange formats The implementation costs in the integration phase are more expensive compared to the visualisation phase.
and cannot be justified on project level. Therefore the benefits need to be derived on company level over several projects.

- **Automation**: routine design task or manufacturing of assemblies (CNC - Computer Numeric Control) for on-site installation are automated. Enables a dramatic increase in design efficiency and effectiveness and dramatic decrease in construction duration. The automation phase need more long term strategic partnership since the implementation costs are high and need to be depreciated over several projects.

For VDC to work well the contracts need incentives to encourage sharing of information between stakeholders in the projects (ibid).

Several research projects and national programs have been launched over the past years in Europe in order to develop model based design guidelines and exchange strategies of BIM data (InPro 2008, DBB 2008, Senatti 2007, Norska BIM). A common approach is that the degree of detailing, the information level or model maturity is increasing through a number of phases from the early stages to detailed design and construction where the required functionalities gradually are mapped onto technical solutions. According to (Delivery D4), a concurrent engineering approach is recommended where the design maturity needs to be synchronised between the involved design disciplines. These maturity levels will form the framework for the design trades and reflect the growing detail level of the design, e.g. BIM maturity A, B, or C, depending on how many different maturity levels are required for the design process. The quality gates will define the level of maturity of the model information and make sure that this information is according to the technical requirements of the design as translated from customers needs.

![Figure 2. A concurrent engineering approach with increasing maturity level (Delivery 4).](image1)

![Figure 3. A formal decision making process (after Baker et al. 2001).](image2)
2.3 Decision making in building design

A formal decision making process can be decomposed in the following steps – see Figure 3 (Baker et al. 2001).

However, in any design situation the designer has to capture the users requirements in order to provide design alternatives that can fulfil the needs and intended use. These requirements or needs are expressed in the user's language, often difficult to translate to specifications of a technical solution. The performance concept presented in Figure 4 offers an intermediate language that makes it possible to match demand and solution – the use of a ‘performance language’ (Jasuja 2005).

![Figure 4. The performance language – a solution to match demand and solution (adapted from Jasuja 2005).](image)

Looking at the requirements originating from the evaluation criteria, design evaluations generally are a multi-criteria decision problem of a high complexity. The criteria themselves are also manifold. They range from subjective criteria that can be described using qualitative statements to precisely measurable criteria, all measured originally with different dimensions or scales. Another challenge for the evaluation methodology comes from the increasing level of detail of the design model along the design process. As a consequence the decision making methodology will have to cope with gaps in the produced design information during the different design phases. A number of formalised decision making methods have been proposed:

**The Analytical Hierarchy Process** (AHP) developed by Saaty (1990) emphasizes the quantitative comparison of alternative solutions. The core of the procedure is that the preferred solution is identified using pair-wise comparisons of alternatives based on their relative performance against the criteria. The method is most useful to support group decisions in teams where people with different specializations are working on complex problems.

**Consider All Facts** (CAF) and **Plus Minus Interesting** (PMI) have been introduced by Edward De Bono (De Bono, 1985) and represent relatively simple, techniques for logic and problem-solving. CAF is a method to possibly take all criteria relevant for a decision into consideration. The PMI method focuses more on the potential impacts of a decision.

**Multi-Attribute Utility Theory** (MAUT) developed by Keeney (Keeney and Raiffa, 1993) is a quantitative comparison method used to combine dissimilar measures of costs, risks, and benefits, along with individual and stakeholder preferences, into high-level, aggregated preferences. Unlike
AHP, MAUT uses utility functions to define how the diversely dimensioned criteria will be transformed into one common, dimensionless scale or metric with a range of 0 to 1.

SMART developed by Edwards and Barron (1994) is a simplified variant of MAUT. The main difference is in the rating of each criterion. Unlike MAUT where the rating has to be calculated with the transformation or utility function, the decision makers directly assign a value between 0 and 1 using the utility function in a qualitative way. By directly assigning the rating values to the criterions, the availability of quantitative data from the alternative becomes optional and the calculation effort is reduced.

The Multi-Attribute Collective Decision Analysis for a Design Initiative (MACDADI) is another multiple criteria decision making method under development by Haymaker and Chachere (2006) with the objective to support the decision process related to design alternatives. According to its developers the MACDADI procedure is inspired by established methods of Decision Analysis, in particular MAUT.

3. RESEARCH PROJECT
3.1 Problem definition
Within the context of InPro we assume that one or more Building Information Models (BIM) build the decision bases on which the decision making method will be applied. The existence of such a structured and data rich model which exceeds a mere graphical 3D representation of the building geometry by additionally containing semantic building elements information offers significant advantages to facilitates the data analysis required using a formal evaluation method (Figure 5).

![Figure 5. Design evaluation using Building Information Models (BIM).](image-url)
For the design evaluation from a BIM, two different opportunities exist:

- Indirect measurement: stimuli from visualizations classified as ordinal, interval or ratio level scales
- Direct measurement: values are taken from the BIM or from analysis/simulations based on the BIM and then transformed into dimensionless scores.

An example of an indirect measurement is the ranking of the architectural appearance of different design alternatives. A direct measurement is the energy performance as calculated from an energy analysis tool. These measurements need to be transferred or normalized from dimensional quantities into dimensionless evaluation results, which can be combined and prioritized into an aggregated result using a traceable mathematical method.

Facing the variety of different methods and strategies offered in the decision theory, it is necessary to further define the characteristics and restrictions of the decision problem. Table 1 summarizes the characteristics of evaluating BIM-based design alternatives.

### Table 1. Characteristics of the decision problem to evaluate BIM-based design alternatives.

<table>
<thead>
<tr>
<th>Characteristics of design alternatives</th>
<th>Characteristics of evaluation criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reasoning about existing design alternatives available as BIMs</td>
<td>Generally multiple criteria have to be evaluated</td>
</tr>
<tr>
<td>Number of design alternatives is generally 2-4 or up to 15 (design competition)</td>
<td>Criteria from different domains lead to complex decisions</td>
</tr>
<tr>
<td>Alternatives differ either significantly in geometry or just in details</td>
<td>Subjective and objective criteria has to be considered</td>
</tr>
<tr>
<td>Explicit data available from BIMs</td>
<td>Criteria have different dimensions</td>
</tr>
</tbody>
</table>

### 3.1 Objectives and limitations

The objective is to define a model based design process that includes life cycle aspects into the early design phase. The model should include a decision making framework to support the decision makers to select the most appropriate design solution based on defined project goals. The study has been limited to energy performance of office buildings.

### 3.2 Research methodology

The research methodology used is a combination of four distinct methods:

1. Literature review: state-of-the-art of energy analysis, building information modelling and decision making methods.
2. Unstructured interviews with clients, contractors and energy consultants: the interviews have been conducted to investigate how energy performance is taken into account in today’s model based design process of office buildings.
3. Workshops and project meetings within the InPro consortium: several workshops and project meetings have been conducted to define and select suitable methods for a model based design process in the early phase.
4. Development of a motivating case: an energy design scenario has been developed in order to demonstrate the developed concept.
This paper describes only the developed framework. The proposed framework is going to be tested and further developed in demonstrations in the InPro project.

4. RESEARCH RESULTS

4.1 Early design phase

The stakeholders in the building process have different interpretation of the term ‘early phase’, Ryd (2008). For the client the ‘early phase’ starts when a business opportunity or a societal demand arises. The initiation of a building project often include a business planning phase for the client where goals, budget, timeframe and organisation is determined before other stakeholders from the AEC (architectural, engineering and construction) sector is involved (see Figure 6). The design of a building is traditionally done in two steps; first a system design of the architectural, structural and installation systems before the solutions is further detailed for construction. After realisation the building is handed over for operations.

![Diagram](image-url)

Figure 6. A building project from the perspective of the client and stakeholders from the AEC sector.

One of the main goals of the InPro project is to shift focus from the detail design to the early design phase where the majority of the decisions are taken that influence the final costs. From a client’s perspective the AEC sector need to be involved earlier in the building process. The AEC sector also needs to involve the client more in the design process to ensure that project goals as expressed by the client are met by the proposed design.

One of the issues that the clients were complaining about “...is that even if we ask for three solutions from the architect in the sketch stage one. We usually just get one usable solution as the architect just put effort into one solution and do the other tow with less effort. There is just one solution which we can try to energy optimised but that mean often optimising windows which cost a lot instead of optimising the design.”

Figure 7 shows the InPro definition of the early design phase. It contains besides business planning and building design (cf. system design in Figure 6) a feasibility design phase where the development team, which includes the client, translate the client’s project goals expressed in user language into values and design requirements expressed in performance language. In this phase it often becomes clear that different design requirements can influence each other or even be conflicting.
Each stage in the early design ends with a quality gate, i.e. go/no-go criteria, where the result is evaluated using a formalised and traceable decision making process. Approved design information, here denoted maturity level, are stored and put under change management control after each quality gate. The circular arrows in the figure indicate the iterative nature of the design process where the design solution is gradually more detailed in each stage during the early design phase.

4.2 The decision making framework

With the characteristics of decision problem we can define the required components or functionalities of a framework to support design decision making as follows.

First, it is essential to know the target values which the design should fulfill from the stakeholders, in particular the client. These values, typically expressed in different dimensions, are often contra dictionary to one another. Second, in order to be able to later comprehensively analyze these critical target values, the stakeholders have to transfer them into dimensionless key performance indicators. To solve the dilemma of multiple and contra dictionary target values, we further need a method to transparently prioritize these KPIs and a mathematical evaluation method to combine KPIs into an overall alternative ranking. Finally, charts or diagrams to visualize the performance of the alternatives regarding each single target value will be required in order to communicate and explain the method’s results in a self explanatory way.

Figure 8 shows a schematic overview of the required components and input for the decision making framework. The following methods have been used in the InPro Smart decision making framework:

- Evaluation method – the MAUT family of evaluation technique for multi attribute decisions problems.
- Prioritization method – the AHP process using pair wise comparison.
- KPI – key performance indicators are normally used to benchmark the success of building projects. In the Smart framework, the KPI has been extended to represent the utility functions used in the MAUT framework.
4.3 Modelling concepts

The InPro model based process is divided in information maturity levels adapted to the decision making process for a specific purpose in a buildings lifecycle. The decisions are based on a specific level of information in the InPro Open Information Environment, here denoted OIE maturity, from which performance indicators can be presented for the main decision makers. This makes it possible to for decision makers to make informed decisions throughout the buildings lifecycle matching solutions against functional needs. The InPro modelling concepts for the proposed model based design process can be summarized as follows:

- The InPro Open Information Environment (OIE) contains the minimum required information needed to support the decision making process at the quality gate in question. The content in the OIE contains in general of a mix of documents, models (design discipline models and aggregated models) and evaluated performance indicators.
- The use of information for e.g. derivation of performance indicators through visualization, simulation, analysis, etc in a specific stage will determine the requirement of information content in the InPro OIE.
- An InPro OIE maturity level defines the approved content of the InPro OIE. Change management procedures are applied on approved maturity levels of the OIE.

InPro defines by default eight lifecycle maturity levels, where levels 0–3 are part of the early design phase. The default OIE maturity levels are:

0. **Goals**, where the business case is identified and normally developed by the client. In this level the overall goals, timeframe, budget and location of the building project are formulated. Also, space program and specific requirements from authorities, client and end-users can be stipulated.

1. **Layout design**, where alternatives regarding building envelope and placement on the premises are selected with regard to constraints given by authorities, the client and geotechnical conditions. Also, gross areas for different functions, room types and relation between functions and alternative use of the building in the future are developed.
2. **Functional design**, gross areas are further detailed into functional spaces in the building (e.g. location of office rooms, meeting rooms, fire compartments, etc). Location of installation shafts and structural parts.

3. **System design**, design of main structural and installation system. Development of building program for approval from local authorities.

4. **Detailed design**, detailing of structural, installation and finishing design and planning information for the realisation stage.

5. **As built**, the OIE level 4 is updated with information from the realisation of the building.

6. **Operation**, normal operational stage where the OIE is updated with information from facility management. If during the operational stage the facility is rebuilt, the OIE maturity levels are repeated starting with as built condition as input.

7. **Demolition**, planning for the demolition and recycling of building parts.

The default mapping of OIE maturity levels versus the building lifecycle phases and quality gates can be fuzzy and overlapping and must be adapted to the specific project.

### 4.4 Design workflow

The design workflow is coordinated between the involved speciality design/analysis disciplines using OIE maturity levels and quality gates for decision making. Figure shows a proposed methodology for the decision making process at a specific stage of the design. It starts from an approved level of maturity set by the previous quality gate (level m). If the previous stage was the layout design (level 1) we now have a basic design of the building envelope and its placement on the site. In the current stage, the target is to create different interior alternatives and select the best alternative from the customer perspective, i.e. to reach maturity level 2.

![Figure 9. Generic workflow process between two levels of maturity.](image-url)

First the development team, the client and different design specialities, decide the mapping of performance requirements from the client(s) goals and requirements that can be evaluated using key performance indicators (KPI) of the design. The KPIs are then
prioritized to guide the team in developing a design strategy. Also the dependencies between the different design specialities must be resolved in the design work using process maps or dedicated design spaces to manage the concurrent design process (Eppinger 1991). After different design alternatives have been created and evaluated, the developed design information and analysis must be checked for consistency, completeness and correctness in the quality assurance gate, c.f. Figure. If the information developed do not pass the QA phase the design information needs to be updated and checked again at the QA gate. The KPIs for the different alternatives are presented together with the overall ranking of the alternatives using the smart decision making tool at the quality gates. If one of the alternatives is selected at the quality gate the new approved set of design variables is added to the model and the design moves to the next stage, otherwise the design loop starts again.

In the example the design workflow started at OIE maturity level 1 and ended with OIE level 2. However, the ending level of OIE maturity is project specific, e.g. the design could very well encompass more than one maturity level ending in this example at level 3.

4.5 Motivating case

The scenario

For the rebuilding of a warehouse to an office building in Helsinki an environmentally conscious Client requests his project team to deliver a very efficient, low-energy consumption design. Having heard about the new energy consumption classes he suggests evaluating the options to create an 'Energy Class A' design. During the feasibility design the client is informed, that for the climatic conditions at the building location, such an energy class cannot be achieved without paying tribute to the indoor climate. From the project team’s experience, the energy target 'Energy Class A' is hard to combine with the required 'indoor climate class S1'. Additionally they suggest balancing the energy savings of various design options with their investment costs. The Client and future building owner agrees to continue with an investigation of different design options during the building design phase. The project manager summarizes the goals for the building design (see Table 2).

Table 2: Client goals expressed in user and performance language.

<table>
<thead>
<tr>
<th>Client Goals</th>
<th>Value (for Client)</th>
<th>KPI</th>
<th>Target value(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy and comfortable indoor climate</td>
<td>Best Indoor Climate</td>
<td>Indoor Climate Class</td>
<td>S1</td>
</tr>
<tr>
<td>Low energy consumption</td>
<td>Energy efficiency</td>
<td>Energy Certificate Class</td>
<td>A - C</td>
</tr>
<tr>
<td>Cost effectiveness (moderate rent level)</td>
<td>Lower operational cost</td>
<td>Payback for investment</td>
<td>Payback time 5-10 years</td>
</tr>
</tbody>
</table>

Design strategy

As a next step the project team starts the discussion of priorities among the above goals with the client. In order to formalize the discussion, the project manager prepares the following evaluation table for the team.
Table 3. Prioritisation of design goals.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Priority</th>
<th>KPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor Climate Class</td>
<td>More important</td>
<td>Energy Certificate Class</td>
</tr>
<tr>
<td>Indoor Climate Class</td>
<td>More important</td>
<td>Energy Certificate Class</td>
</tr>
<tr>
<td>Energy Certificate Class</td>
<td>Equally important</td>
<td>Payback for investment</td>
</tr>
</tbody>
</table>

The priority corresponds to weight values in the evaluation matrix in Table 4 according to a nine-point scale (Saaty, 1990):

- Equally important ..................... 1
- More important .......................... 3
- Strongly more important ............... 5
- Very strongly more important .......... 7
- Overwhelmingly more important ....... 9

Table 4. Evaluation matrix for calculation of the priority vector.

<table>
<thead>
<tr>
<th>Evaluation Matrix</th>
<th>Indoor Climate Class</th>
<th>Energy Certificate Class</th>
<th>Payback for investment</th>
<th>Eigenvector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor Climate Class</td>
<td>1</td>
<td>1/3</td>
<td>3/1</td>
<td>0.60</td>
</tr>
<tr>
<td>Energy Certificate Class</td>
<td>1/3</td>
<td>1</td>
<td>1</td>
<td>0.20</td>
</tr>
<tr>
<td>Payback for investment</td>
<td>1/3</td>
<td>1</td>
<td>1</td>
<td>0.20</td>
</tr>
<tr>
<td>Total</td>
<td>1,00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When the first criterion in the left column is less important than the second criterion, the weight value becomes reciprocal. The normalized eigenvector of the weights matrix give the priority vector. After having set the priorities, the target values with tolerances and therefore the boundary conditions for the design alternatives have to be discussed among the project team. The Smart decision making method requires assigning a utility function for each KPI respectively criterion to relate values measured for the different design alternatives to a performance scale between 0 to 100% fulfilment of the client demands/desires (see Figure 10).
Figure 10. Rating of target values between minimum and desired functionality using utility functions (adapted from Ryd (2008) and Schreyer et al (2009)).

Together with the project team the following ratings to optional target value ranges are determined by the client, see Figure 11. An important criterion for the Client is the indoor climate class since he is convinced that the productivity of his company will be strongly influenced by an excellent indoor environment. He is willing to allow some tolerance below class S1 but not lower than S2. For the criterion ‘Energy Class’ class A would fulfil the desired requirements fully. The rating for values B to D is decreasing disproportional and values beyond class D were not accepted by the Client. Regarding the payback time for the total investment, the Client is willing to spend more if the additional investment doesn’t exceed a payback time of 15 years. The optimum rating for the economically most sustainable design is therefore assigned when the payback for investment will not exceed 5 years.

Figure 11. Utility functions for the KPI in the energy design scenario.

**Design and analysis**

At the design kick-off meeting the team reflects the consequences of the design requirement analysis for the design strategy and the technical solutions that have to be investigated. Taking the Client priorities into consideration, the preference of the indoor air quality will govern the design strategy. However, at the same time the requirement for an economical reasonable design solution within the boundaries given by the Client will have to be fulfilled, a criterion, which is also influenced by finding technical solution with low energy consumption. A couple of days later, the design team have created and analysed the three Building Information Models summarized in Figure 12.
The result of the energy analysis is summarized in Table 5. The three alternatives have the same Indoor Climate Class and the Payback Time for the investment in energy saving design #2 and #3 was estimated to 8 and 12 years respectively, (design #1 is the reference, i.e. 0 years payback).

Table 5. Results from energy analyses of the three design alternatives.

<table>
<thead>
<tr>
<th>Design #1</th>
<th>Energy cons. [MWh/a]</th>
<th>Design #2</th>
<th>Energy cons. [MWh/a]</th>
<th>Design #3</th>
<th>Energy cons. [MWh/a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating</td>
<td>528,5</td>
<td>Space heating</td>
<td>307,2</td>
<td>Space heating</td>
<td>306,9</td>
</tr>
<tr>
<td>AC-heating</td>
<td>321,4</td>
<td>AC-heating</td>
<td>310,7</td>
<td>AC-heating</td>
<td>180,7</td>
</tr>
<tr>
<td>Hot water heating</td>
<td>66,2</td>
<td>Hot water heating</td>
<td>66,2</td>
<td>Hot water heating</td>
<td>66,2</td>
</tr>
<tr>
<td>Total heating energy</td>
<td>916,1</td>
<td>Total heating energy</td>
<td>684,1</td>
<td>Total heating energy</td>
<td>853,4</td>
</tr>
<tr>
<td>Equipment el.</td>
<td>23,5</td>
<td>Equipment el.</td>
<td>23,5</td>
<td>Equipment el.</td>
<td>23,5</td>
</tr>
<tr>
<td>Lighting el.</td>
<td>211,1</td>
<td>Lighting el.</td>
<td>211,5</td>
<td>Lighting el.</td>
<td>211,1</td>
</tr>
<tr>
<td>HVAC el.</td>
<td>212</td>
<td>HVAC el.</td>
<td>211,5</td>
<td>HVAC el.</td>
<td>211,4</td>
</tr>
<tr>
<td>Total electricity</td>
<td>446,6</td>
<td>Total electricity</td>
<td>446,1</td>
<td>Total electricity</td>
<td>445,9</td>
</tr>
<tr>
<td>Cooling energy</td>
<td>29,5</td>
<td>Cooling energy</td>
<td>36,5</td>
<td>Cooling energy</td>
<td>36,6</td>
</tr>
<tr>
<td>Total energy consumption</td>
<td>1392,2</td>
<td>Total energy consumption</td>
<td>1166,7</td>
<td>Total energy consumption</td>
<td>1036,4</td>
</tr>
<tr>
<td>Energy efficiency rate [kWh/m²]</td>
<td>123</td>
<td>Energy efficiency rate [kWh/m²]</td>
<td>103</td>
<td>Energy efficiency rate [kWh/m²]</td>
<td>92</td>
</tr>
<tr>
<td>Class</td>
<td>C</td>
<td>Class</td>
<td>B</td>
<td>Class</td>
<td>B</td>
</tr>
</tbody>
</table>

Decision making at the quality gate
After the model information been quality assured by the information management the project manager prepares the project meeting at the quality gate and calculates the KPI ratings for the three alternatives from the utility functions. The result is also visualised in a spider diagram – see Figure 13.
After the individual KPI performance results have been calculated and visualized, the priorities are taken into consideration in order to calculate the total evaluation result for each design alternative (see Table 6). In the final design meeting the team discusses the results of the analysis with the Client. Under the conditions given, alternative 2 which fulfils the design requirements with a rate of 95%, offers the best performance. The improvements for lower energy consumption by the heat recovery systems in alternative 3 do not payoff fast enough to balance the additional investment. On the other hand, the improvement by a higher insulation and tightness of the building shell on the energy consumptions results in a payback period which is still within the tolerance level of the Client.

Table 6. Total rating of the three design alternatives.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Rating/priority</th>
<th>Design #1</th>
<th>Design #2</th>
<th>Design #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor comfort</td>
<td>Rating</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Priority</td>
<td>0,60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy consumption</td>
<td>Rating</td>
<td>50%</td>
<td>80%</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Priority</td>
<td>0,20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Payback</td>
<td>Rating</td>
<td>100%</td>
<td>90%</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td>Priority</td>
<td>0,20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total rating</td>
<td>∑Rating x Priority</td>
<td>80%</td>
<td>95%</td>
<td>93%</td>
</tr>
</tbody>
</table>

The total performance chart together with the individual KPI results for each alternative help the design team to transparently explain the evaluation results, their design decisions and recommendations to the Client, thus enabling him to make an informed decision or, if necessary, to reconsider the initial priorities.

The total rating, here 95%, can also serve as a KPI for the design process as it reflects the fulfilment of the client goals/values.

5. CONCLUSIONS
The InPro lifecycle model-based framework offers a new methodology for communication energy consumption through each stage of the building lifecycle. The benefits with this
BIM-based lifecycle design include that such information as building geometry, structure, material, installation and functional use is stored in the BIM model. This reduces time and cost for analysis of energy lifecycle for the building. Furthermore, the flexibility of design changes increases as the changes are easier to arrange. Analysing and optimising the energy performance of the design at the early stage is a significant advantage of this framework.

The benefit of adapting the decision making framework into this model-based process is the transparency of the design decisions with regard to the set goals at the beginning of the project. The construction client is more involved in the early design process. With the help of the decision making process the decision rational during design is based on a more formal, hence transparent procedure than the biased process we often find within project teams, today. The possibility of including different criteria in the decision making process makes this framework very flexible. This process further reflects the necessary compromises during the design and interdependences of the different goals. However, it does not uncover the interdependences and influences of the parameters. These parameters must be still interpreted further by the specialists. By choosing appropriate KPIs, a long-term improvement process for the enterprise can be possible. The software conversion of the decision making framework is relative trivial.

The InPro life cycle model-based process is a theoretical framework that needs to be further tested in practice.

6. ACKNOWLEDGEMENT

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7. REFERENCES


Ryd, N., (2008), Initiating building projects – clients’ and architects’ front-end management of projects, Department of Architecture, Chalmers University of Technology.

