ABSTRACT

Design process can be characterised as a series of decisions concerning multiple requirements and various solutions. Current design management practises don't often include use of formal tools to assist in decision-making concerning the life cycle performance of the facility. Quality Function Deployment (QFD) is a tool that has been successfully applied in other industries in product development projects. It offers a systematic approach to match the customer expectations with the product features, and to document decisions in the design process. QFD, consisting of house of quality matrices, can be seen as a team decision making tool to achieve common understanding and commitment to performance-based design objectives and prioritised characters of design solutions.

In the framework of International Energy Agency (IEA) task 23 design trade-off tools are developed and implemented to support design of eco-efficient buildings. The basic performance criteria for buildings are defined to be life cycle cost, resource use, architectural quality, indoor quality, environmental loading and functionality.

This paper describes experiences from applying QFD in the performance-based decision-making process using the IEA task 23 criteria as a starting point. A systematic approach in viewing the client's needs is found very helpful. QFD is used for evaluation of the requirements against the properties of a building and to harmonise the project team members' views and ideas. It also emphasises the importance of the whole design and construction process, and group work as a tool to reach the targets set for the project. The decision making process becomes more transparent enabling improving traceability of decisions concerning different design alternatives.

KEYWORDS

Decision-making; performance approach; quality function deployment.

INTRODUCTION

Construction in the last decades has largely based on technical solutions, that architects and engineers were willing to implement. Buildings became rather fixed units, at the worst optimised for cost-efficient production. Functionality and adaptability for user's changing needs was low. In future construction, both housing and commercial building, the needs and activities of the users have the highest priority.

Design process can be characterized as a series of decisions concerning multiple requirements and various solutions. Current design management practice doesn't often include use of formal tools to assist in decision-making concerning the life cycle behavior of the facility. The building user's need and willingness to influence the design is increasing. A systematic approach in viewing the client's needs is a necessity. Without a proper documentation in the early design phase, user requirements tend to vanish in the process.

In the framework of International Energy Agency (IEA) task 23 (IEA 1998) design trade-off tools are developed and implemented to support design of eco-efficient buildings. The basic performance
criteria for buildings are there defined to be life cycle cost, resource use, architectural quality, indoor quality, environmental loading and functionality. The primary results of the work will be guidelines, methods and tools for use by designers in the early stages of design. These tools are meant to help the design team to verify the conformity of the design with the objectives.

Ecology is a driving way of thinking in the future construction. It will direct the decision making in the design process. In the construction of today, existing technical solutions are the way towards a completed building. Eco-efficient construction emphasises the performance properties of the building. Every building has a first owner or user, for whose activities the building is constructed. In the project-programming phase, the performance-based properties of the building are described. The design process should then create a model to fulfil these requirements. A clear analysis of the properties brings along a new view to the process. VTT Building Technology has developed a requirement’s classification for buildings. Requirements can be set and prioritised depending on the view to the project, figure 1.

The performance approach should lead to client oriented construction and facilitate the clients to obtain buildings that meet their needs. It also means that more effort is needed in the early phases of design. It may require changes to the traditional working procedures, new competition modes and agreements, maybe even a definition for a new language and certainly increased communication along the design process.

Some well-identified problems related to design process can be listed as follows:
- how to understand what the client really needs and what can be achieved
- how to interpret and to express the needs in a form of requirements
- how to verify that the design is conform with the requirements
- how to execute the design in a productive and qualitative way.

This paper describes experiences from applying QFD in the decision-making process in building design using the IEA task 23 criteria as a starting point. Quality Function Deployment (QFD) offered a systematic approach to match the customer expectations with the project features, and to document decisions in the design process. Two case studies are shortly presented. One live pilot aimed at setting design guidelines for a future home prototype constructed for housing fair. The second pilot deals with design priorities at an environmental-friendly nursery school based on the design brief.
QUALITY FUNCTION DEPLOYMENT AS A TRADE-OFF TOOL

In industrial engineering, manufacturing companies have successfully applied Concurrent Engineering tools (Koskela & Huovila et al., 1997), e.g. Quality Function Deployment (Akao, 1990) to determine customers' needs for the features of the product into design at its early stages of development, to integrate concurrent design of products and their related processes, and to consider all elements of the product life cycle. Customer-oriented “champion products” may also be priced higher than their competitors, and still become as market leaders. In spite of its “success stories” in other industries during the past decade, QFD has been little applied in construction. Examples from Japan, United States, Finland, Sweden and Chile show, however, its potential also in building design. (Huovila et al. 1997)

QFD provides an empty matrix (House of Quality, figure 2) to be filled with customer requirements and their importance in the rows along the left hand side, properties of the solutions in the columns along the top portion. The center describes the matrix-relationship of requirements and corresponding solutions. The importance measures (weight factors) are at the bottom, and the right hand side of the box shows the evaluation of competing alternatives.

The following phases of a construction process are identified potential for QFD implementation in construction, figure 3:

1 PROGRAMMING: Customers’ requirements for the building and design objectives
2 DESIGN: Design objectives and construction drawings
3 PRODUCTION: Construction drawings and production plans
4 CONSTRUCTION: Production plans and construction phases.
MULTI-CRITERIA DECISION-MAKING AS A TRADE-OFF TOOL

There are many criteria to be considered in a design process. Some of the criteria are qualitative in nature and some quantitative in nature. The criteria are expressed in different terms or different units. IEA task 23 has developed a trade-off tool where six basic requirements can be weighted and scored. The idea is to use numeric values and visualize the result in a form of a hexagon, where the dimensions (between 0 and 1) indicate how well the objective is met. Design team uses a tool to organize information required for decision-making, and to select one design alternative from two or three being proposed in the design briefing process. Figure 4 shows the multi-criteria decision-making method integrated into the framework of one cycle of an iterative design process. A computer program, MCDM-23, leads to a worksheet for each alternative scheme being considered and a star diagram, figure5.

stop (select solution)

Figure 4. A multi-criteria decision-making process in a building design framework (IEA 1998).
CASE 1: VILLA 2000

The design of Villa 2000 was teamwork. Each designer had a possibility to influence decision-making throughout the whole design process. A design briefing using QFD as a working tool was organised to capture the owner’s requirements and to set design guidelines for Villa 2000. The exercise was conducted together with ten experts of different backgrounds. The following objectives were set for the working session:

- to share common understanding of the performance-based objectives of the end product (a building to be designed and constructed)
- to prioritize the project objectives
- to strive for innovative design solutions that meet these objectives.

The IEA Task 23 criteria were expressed in a form of performance requirements with the team created sub-requirements. Each requirement was given a weight (scale 1 to 5) depending on its commonly accepted importance. The potential design solutions were then expressed in from of properties, and their correlation with the requirement was given (scale 0, 1, 3 or 9). The QFD spreadsheet tool summarizes numeric values of the properties in the bottom of matrix by multiplying the correlation 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 first matrix (figure 6) 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 (figure 7) shows the structured approach in the design process based on the selection made in phase 1. The importance of the whole design and construction
process was recognised as the key to fulfil the requirements, and the functionality and adaptability of the house as the key to future housing.

### PHASE 1

**Requirements**

- **functionality**
  - Utilisability
  - Adaptability
  - Maintainability
- **environmental loading**
  - Operation
  - Construction
- **resource use**
  - Energy
  - Water
  - Materials
- **life cycle cost**
  - Investment cost
  - Operating cost
  - Maintenance cost
- **indoor quality**
  - Acoustic comfort
  - Thermal comfort
  - Lighting
  - Indoor climate
- **architecture**
  - Architecture

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**Properties**

- adaptability, simple interfaces, re-usable fair house
- indoor conditions, responds to the environment
- economy, resale value
- environmental, autonomy, total ecology
- constructability
- architecture

**Figure 6. Design objectives for a housing project, phase 1 (Nieminen & Huovila 2000).**

### PHASE 2

**Requirements**

- **adaptable, simple interfaces, re-usable fair house**
- **indoor conditions, responds to the environment**
- **economy, resale value**
- **environmental, autonomy, total ecology**
- **constructability**
- **architecture**

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**Properties**

- SPACE
- PROCESS
- STRUCTURES
- MATERIALS
- ENERGY
- EQUIPMENT

**CASE 2: NURSERY SCHOOL**

The second QFD example was to set the project objectives with a view to the building user’s needs and requirements and, to show how the chosen criteria and the view, the user’s view affect the results.
QFD matrix was used to capture, record and verify the client’s requirements and, to test the dependency between the requirements and the properties of the introduced building concept.

The project used in the test is a nursery school for about 100 children to be built in the year 2000. The design process of the building is to be finished towards the end of 1999, based on an architectural competition. The nursery school Merituuli will be built in a new suburban housing area, a former industrial area, where the basic infrastructure has already been developed (streets, access to main roads, district heating net, etc.). The location of the area is very close to the city of Helsinki with a good public access to the city, a fact that has made the area very popular especially among young families. This has also grown to be a design feature for the nursery school building and it’s connection to the surrounding housing area.

The building will serve as nursery school daytime, and in the evening as a meeting point for local inhabitant activities. The total building area is 1260 m² one story. The owner of the building is the City of Helsinki, and the Construction Management Division (HKR) of the City of Helsinki constructs the building.

In a number development sessions, arranged both between the client and VTT in the beginning of the project and, later on between the designers, project management and VTT, the project goals and limits were discussed and the requirements were set. The decision making in the project was tested against the main criteria adopted from the IEA Task 23 framework. The results of the design briefing sessions were used as building owner defined sub-requirements in compiling the QFD matrix (figure 8).

![Table]

**Figure 8. Design priorities for a nursery school (Nieminen & Huovila 2000).**
According to the QFD results, the main properties of the nursery school building corresponding to the given requirements are district heat, bicycle access to the site, cleanable ventilation ductwork, multi-use playrooms for children and low-energy building envelope.

Environmental goals of the project prioritized as the most important properties. Even though the builder has an environmental program to support sustainable construction, it is not surprising, that the requirements dealing with functionality or air quality in a nursery school are dominating the pre-design process.

MCDM-23 tool was used to evaluate the introduced technical design solution and to compare the design with typical existing nursery schools. Also a low-energy concept for the nursery school was developed and analyzed accordingly. The proposed solution (basic design, figure 9) brings along improvements compared to typical nursery school. By improving the energy efficiency of the building, both user friendliness (functionality, indoor climate) and environmental properties and life cycle costs are improved.

Figure 9. Analysis of two design solution and comparison to properties of a typical nursery school building.
FURTHER DEVELOPMENT

QFD can be seen as a general-purpose tool that can be used for improving products and processes, or to support decision-making in strategic planning. As a simple spreadsheet matrix, the House of Quality can also serve as an interface to be integrated with other tools.

On example of such matrix tools is the Green Building Challenge (GBC 2000, figure 10) where one could think of making a preliminary assessment of the building performance with it and then continue the product and system development and design with QFD. Or, the preliminary objectives could be verified against strategic priorities first with QFD, and then continued with GBC to use those priorities weighed against the technical solutions of buildings in order to get the building assessed.

Figure 10. Green Building Challenge 2000.
to achieve both a performance profile of those properties together with the specifications in a textual form to be used and completed as a design brief.

The EcoProP interface has been modified to use the IEA task 23 properties structure as a starting point, to show the performance profile, figure 11. It has also been linked to QFD so that the properties that have been given values can be taken as requirements in the QFD House of Quality matrix.

![EcoProP Interface](image)

Figure 11. An integrated EcoProP - IEA task 23 - QFD tool.

CONCLUSIONS

Design process can be characterized as a series of decisions concerning multiple requirements and various solutions. Current design management practice doesn't often include use of formal tools to assist in decision-making concerning the life cycle behavior of the facility. The building user’s need and willingness to influence the design is increasing. Systematic procedures together with the performance concept and formal tools are chosen as an approach when striving for facilities that will be conform during their life cycle with owners’ and users’ needs.

In a multi criteria decision making process, the owner’s view to the project should be of first importance. A systematic approach in viewing the client’s needs (like QFD in this case) is necessary. QFD is a method for evaluation of the requirements against the properties of a building. QFD can be used to harmonize the project team member’s (clients, designers, researchers) views and ideas. It also emphasizes the importance of the whole design and construction process, and group work as a tool to reach the targets set for the project.

A formal tool is very helpful in managing the decision-making especially when the design team members come from different backgrounds and traditions in building design. The decision making process is transparent, and the decisions and different design alternatives are traceable.

In a design of a school or a nursery, the functional properties of a building have the priority over the technical aspects. The properties that are the most crucial for the users - children, their parents and the school staff - were emphasized. The highest priority was given to the indoor quality in terms of air purity and illumination and functionality in terms of safety in use. Low emission rates from building materials were considered as the most important features of environmental loading. The building owner’s commitments to sustainable construction are arising in terms of functionality and indoor quality. The original cost estimate for the school building limits the possibilities to perform actions outside the functional properties of the building.
REFERENCES


