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QFD for the building and construction industry

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Not only is the clients' distrust towards producers a problem that the Building and Construction (BC) industry has to deal with, caused by exceeding costs and unsatisfactory fulfilment of requirements, but also producers struggle to survive within the highly competitive traditional BC-market system with very low profit margins focusing on the lowest price rather than on the highest value.
There is a need for a market change and for models and systems that can address the value, costs and performance of BC projects in order to provide a service industry that can satisfy the current needs. Therefore this paper looks at the management method Quality Function Deployment (QFD), which focuses on satisfying the clients' needs. QFD has already proven to be useful in other industries. This paper shows that QFD is a suitable method for the BC industry and its application to BC projects can help improving the current system.

Keywords: Keywords: QFD, house of quality, building and construction, value, costumer

1 Introduction

Products in the BC industry are mostly made –to order and created for the ultimate purpose they should meet. Developing a new product, while only knowing its general purpose, is possible. But when no detailed requirements are established it becomes hard to create the product that exactly meets the customer's needs.
The traditional way of competing, based on the lowest price, results in less profit for the companies, maybe bad quality results and therefore the need for additional work. This leads to higher costs and is dissatisfying not only to the company but also to the client. In large-scale projects a lot of companies have to work together and all of them have to be aware of what they are responsible for and when they can build their part of the project. Communication is the issue in this case where failures can occur and lead to delays and wrong information flows. Delays result in a raise of costs, whereas wrong information flow can cause wrong placement of a part of the structure and thus a failure in quality.
Because of the aforementioned issues a major change has to be made in the BC industry's way of thinking and working. The cost-driven approach as it exists today has to be shifted to a value-driven approach where the needs of future clients can be taken into account at early stages of a construction project. Unsatisfying results and the need for changes, after a project is finished, should be reduced. Therefore the whole industry has to become more aware of the issue of quality. But as Andy Warhol once said: '*They always say that time changes things, but you actually have to change them yourself*.'[1] This can perfectly be applied to the world of BC. Needs and requirements of customers may change, but the industry itself is very conservative and rather stays with the old and well-tried methods.

1 **Warhol, A.** (1975). The Philosophy of Andy Warhol, New York, p. 113

The change to a value-driven approach of BC has to be made by the industry, because it will not change itself.
The aim of this paper is to show if the method Quality Function Deployment (QFD), which has proven to be useful in other industries, can be applied to the BC industry. Therefore a description of the common practice of projects in the BC industry is given and analysed. The observation of the whole lifecycle of a construction shows that the awareness of the requirements to the construction has to be enhanced. After presenting the problem in detail the method of QFD is illustrated. Furthermore, this approach is analysed regarding its practical application to BC projects in order to solve the problems given in the first chapters. Finally, advantages and disadvantages of QFD in the BC industry, as well as some ideas for further research on this subject are summarized.

2 The Building and Construction (BC) Industry

Products of the BC industry build the technical foundation of our modern world. The structure of a house, streets, tunnels and water mains are things without which one can not imagine today's live. This chapter describes the main stakeholders involved and a typical process phasing of BC projects. The characteristics and difficulties arising in this industry are subsequently explained. In order to provide a good overview, the whole supply chain is described by means of a value-cost model.

2.1 Characteristics of the BC industry

The traditional system for building contracts is based on a public call for tenders. In most of the cases the decisive criterion for issuing the award of the contract is the lowest price. Consequently, companies are competing on price and not on quality. As a result, especially in large-scale, one-of-a-kind, BC projects they are facing high failure costs. The main sources for failure costs are building and construction errors, time delays and requirement changes. Also miscommunication leads to high additional costs.[2]
Figure 1 illustrates the common division of a typical building project in the Netherlands. A project is preceded by its needs and ideas. The principal has to go through an orientation phase and an evaluation of the feasibility of these ideas. By order of the principal a concept design has to be made by a designer. Thereafter a preliminary design followed by the detailed planning is made. Subsequent to the design phase all relevant information is passed over from the designer to the contractor, who is in charge of executing the construction. The completed building or structure is then operated and maintained in which the lifetime and thus the time of operation and maintenance can vary between weeks and several decades. In the end the structure can either be reused for other purposes or it can be demolished.[3]
According to Özsariyildiz the BC industry is fragmented and complex with many small companies.[4] It is human-oriented and the one-of-a-kind products and processes are linear and highly influenced by external factors. There is a lack of strong industry leaders and the knowledge feedback and forward mechanisms as well as the reuse of information and knowledge are weak parts of the industry. Although the companies depend on each other and are interrelated to each other, the BC industry is highly competitive with low profits.

2 **Dado, E.** (2002). ICT-Enabled Communication and Co-operation in Large-Scale On-Site Construction Projects, Delft, pp. 7-9
3 **Dreschler, M.** (2009). Phd TU Delft: Fair competition: How to apply the 'economically most advantageous Tender' (EMAT) award mechanism in the Dutch construction industry, Delft, p. 28
4 **Özsariyildiz, S.S.** (2006). Inception Support for Large-Scale Construction Projects, Delft, p. 5

With these characteristics in mind, many clients no longer agree to not being in control and they do not accept the high costs of failure. Increasing pressure to shorten lead times and deliver value for money is the general result. In addition, the society has higher demands on safety, environment, energy and sustainability. In order to cope with these increasing requirements there is the need to rethink the actual system, optimise it, change it and maybe adapt systems and tools from the field of management and organisation, for the BC industry.[5]

5 **Dado, E.** (2002). op cit p. 8

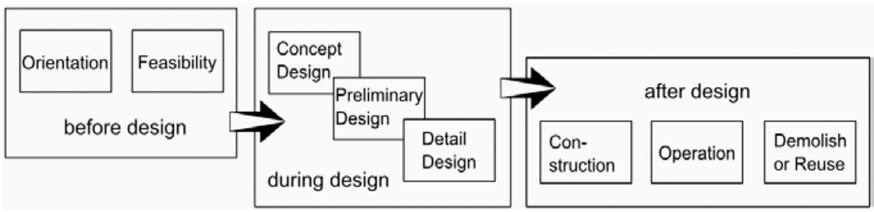

Figure 1 life-cycle stages of a BC project

2.2 Construction supply chain

In the BC industry there are all kinds of actors around a project who all exert influence on the end product. In the traditional way the client specifies his or her requirements, the designer makes the design and the contractor executes the work. In most cases the client is not an expert and therefore only the ultimate needs are roughly specified because he is not aware of all the possibilities and opportunities. In the current situation of the BC industry the client defines a facility for which the value is fixed and associated with a cost-estimation. But as technical difficulties arise during construction, a client, who is not an expert, has a lack of understanding and therefore will not comprehend a claim of additional costs. Consequently dissatisfaction arises at the client's side.

The construction supply chains are make-to-order and demand-driven. Mostly the products are one-of-a-kind and are produced on-site. Generally speaking, this leads to a double transfer of information: from the client to the designer and from the designer to the contractor. Often one party is just throwing all the information 'over the wall' towards the next party. The realisation of the client's wishes of a proposed facility mostly depends on how the requirements for that facility are translated into design requirements.[6]

6 **Kamara, J.M.** and **Anumba, C.J.** (1999). Client requirements processing in construction: a new approach using QFD, Journal of Architectural Engineering, p. 1

This situation leads to a demanding relation between the client and the designer. To better understand the clients' needs the design companies have to be involved in an early stage of the project. A general trend foresees that responsibilities will become more integrated over the whole life cycle of a project in order to deliver high value to the clients.[7] On the international market especially, but not only, skills like marketing, selling and financial management have to be of influence within the company. In order to be competitive, bigger companies invest in expansion and offer a broader range of services, whereas smaller companies tend to specialise in niche services.

7 **Dado, E.** (2002). op cit pp. 10-11

Traditionally, there is a very low level of standardisation in the BC industry. Most projects are top-down client specific solutions and consist of a lot of small elements and components. These components (and/or services) are delivered by supplying companies to the general contractor on a project-by-project basis. Nowadays, project and construction managers often work together with their

8 op cit p. 15
9 op cit pp. 15-16
10 Ridder, H. de (2007). Het Living Building Concept, Paper series 1: Design and construction processes, TU Delft
11 Nederveen van S. et al (2009). Value-oriented industrial building for a sustainable future, Open building manufacturing: key technologies, applications and industrial cases, TU Delft, p. 21
12 op cit p. 24
13 Akao, Y. (1997). QFD: past, present, future, International Symposium on QFD, Linköping, p. 1

own network of suppliers, which are judged mainly on their price competitiveness or on experiences from the past, on a long-term basis.[8]
De Ridder points out the need for a bottom-up ‘push market’, with supply driven solutions. In such a market suppliers would take over the role of traditional construction companies. As they are nowadays often responsible for assembling large parts of a building (foundation, building core, internal finishes), they could also deliver complete construction services. And as they are concerned about their independence from large construction companies anyway, they could sell their services to the client directly. By offering value-added products, suppliers can become more competitive and continuously improve their products (product innovation). An increasing level of product standardisation, by developing product-families and product-modules, would be the result. Unidek, a Netherlands-based company, offers a complete service for prefabrication and assembly of small office buildings to their clients.[9 10 11]
As stated above the BC industry has to change. In order to create more client satisfaction and appreciation from users and society, a value-driven approach should be used instead of a cost-driven approach. According to the value-price-cost model from van Nederveen et al, the value has to be higher than the price, in order to assure some benefit for the client.[12] Furthermore, the price has to be higher than the costs otherwise the provider has no profit. To enhance the change from static building methods towards a dynamic and adaptable construction system, there is a demand for methods and instruments, which can address the value, costs and performance of BC projects. Thereby the development of a service industry that can control the current needs should be possible.
As it has proven to be successful in other industries, QFD might be able to provide the necessary background for more flexibility within BC projects. No guarantee for a successful application of QFD in the BC industry can be given, but within the next chapters the high potential for its opportunities of implementation will emerge.

3 What is QFD?

One of the most important characteristics of a product is that the customer likes it. A customer likes a product when it fulfils his needs and meets the requirements he expected from the product. Therefore a lot of technologies in the field of management, organisation and manufacturing have been developed and proved to work for product development and improvement. In this chapter an introduction is given to the management tool QFD, which is a ‘proven’ approach for translating costumer needs into design solutions.

3.1 History of QFD

QFD was developed in Japan in the sixties by Yoji Akao and Shigeru Mizuno as a quality system. It focuses on the delivery of products and services for efficient customer satisfaction. The method aims to bring the ‘Voice of the client’ into the product. After World War II, Japanese companies developed their products mainly through imitation and copying. In the 1960s, Japanese companies changed their strategies and based their product development on their own ideas. In this environment QFD came to life.[13]
In this time the Japanese automobile industry grew rapidly and companies started

to see the importance of design quality. Quality control process charts were used mainly during or after the product development rather than at an earlier stage or at inception. In 1966 Bridgestone Tires Japan presented the first application of these charts at a large scale and introduced a listing of processing assurance items to identify the client's wishes and quality characteristics.[14] This method was developed further to a real quality chart that can be named the core of the QFD methodology. It was established at the Kobe shipyards of Mitsubishi Heavy Industries in 1972.

Important input came from Value Engineering, which is a way to visualize the functions of a product and can be especially useful when creating a "Quality Assurance activity table", a part of the QA system documentation. Today's QFD was developed and took shape from many different flows and concepts, including Quality Assurance, Quality Deployment, Value Engineering and the Quality Chart.[15]

It took some time before QFD was widely spread. The majority of the applications were in the transportation and high-tech branch, where the main Japanese export products came from. It took till 1983 before it was introduced in Chicago by the Cambridge Corporation along with Akao and Kogure and became further known in the US through an article in 'Quality Progress'.[16 17]

The application and interest in QFD grew fast because companies were accustomed to quality circles already. Consequently, it proved useful to develop a competitive advantage in quality, costs, development cycle time and delivery. [18]

Phonetically the Japanese characters for QFD stand for:

- Hinshitsu: meaning quality, features or attributes
- Kino: meaning function or mechanization
- Tenkai: meaning deployment, diffusion, development or evolution

As the first translators chose the words 'Quality', 'Function' and 'Deployment', this notation got stuck in the USA and Europe.[19]

3.2 The House of Quality

QFD is a systematic process, providing a structure for developing a product that meets the customer's requirements. Based on these requirements the so-called "House of Quality" is built. For a typical application of QFD between 30 and 100 requirements of the customers are collected by means of market research activities. They have to be translated into quality characteristics, which can be rated and observed. In addition, they are brought into relationship with the walls of the house representing the rating of importance of every required attribute and the measurable technical specifications for achieving the user demands.[20 21 22] According to Hauser and Clausing "The marketing domain tells us what to do, the engineering domain tells us how to do it."[23]

The body of the house is the interrelationship matrix connecting the aforementioned elements to each other. With different symbols the strength of the correlation can be visualized. Other characteristics like for example the degree of technical difficulty, competitive analysis and sales points can also be included in the house of quality depending on the range of the project. The roof of the house is the most important part and shows the balance of trade-offs between all technical features.[24] The interaction points of all technical specifications and their influence (positive or negative) on each other is visualised here.[25 26]

14 op cit p. 2
15 ibid
16 op cit p. 3
17 **Shillito, L.M.** (1994). Advanced QFD-Linking Technology to Market and Company Needs, John Wiley & Sons, New York, p. 1
18 ibid
19 **Cohen, L.** (1995). Quality Function Deployment: How to make QFD work for you, Addison-Wesley, Reading, MA, p. 7
20 **Hauser, J.R.** and **Clausing, D.** (1988). The House of Quality, p. 6
21 op cit p. 5
22 **Akao, Y.** (1998). Quality Function Deployment: Integrating Customer Requirements into Product Design, Productivity Press, Cambridge, MA, p. 5
23 **Bossert, J.L.** (1991). Quality Function Deployment: A Practioner's Approach, Marcel Dekker, NY, p. 1
24 ibid
25 **Akao, Y.** (1998). op cit pp. 6-7
26 **Hauser, J.R.** and **Clausing, D.** (1988). op cit p. 7

27 Bossert, J.L. (1991). op cit p. 5
28 op cit pp 5-6
29 Hauser, J.R. and **Clausing, D.** (1988). op cit pp. 11-13
30 Shillito, L.M. (1994). op cit p.2

At the first glance a detailed QFD matrix looks quite confusing and overloaded with information, but looking at it from a distance makes it possible to get a general view of all the things going on. Figure 2 shows a rough diagram of the house of quality and its contents.[27]

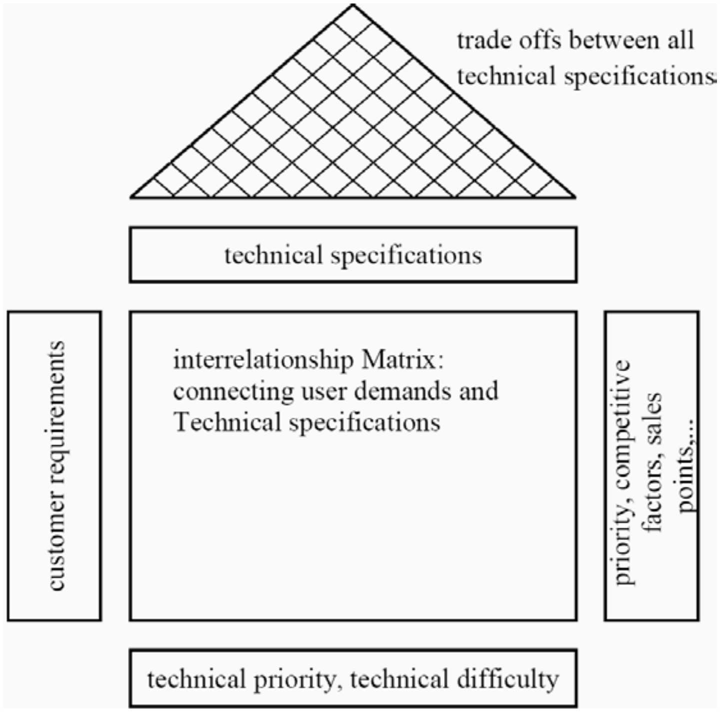

Figure 2 general overview of the house of quality (after Bossert (1991). op cit p. 7 and Kamara & Anumba (1999). op cit p. 10)

The planning phase of a project might take longer if QFD is in use, but in return the whole duration of the project will be shorter due to reduced implementation time. With this system it is possible to focus on the specifications which are most important for the customer's satisfaction whereas the other parts, rated as not so important, can be processed with lower priority.[28] Furthermore with QFD the communication within the project can be improved and decisions can be taken based on the prioritization of needs and technical possibilities.

3.3 General view

As the house of quality can be applied in general to find clear relations between manufacturing functions and customer satisfaction, in a next step more interlaced houses, as shown in Figure 3, can be built. For the second house the engineering properties of the first house (the house of quality) will become the requirements. They have to be connected to product or part characteristics telling how to reach the requirements. In the third house these characteristics are the requirements, which will be connected to manufacturing operations. In the last step manufacturing operations are connected to specific operations and controls.[29] With these interlaced houses the voice of the costumer can be brought to every stage of the project from development over planning to production and product service.[30]

31 Cohen, L. (1995). op cit pp. 180-181
32 op cit p. 182
33 op cit p. 21

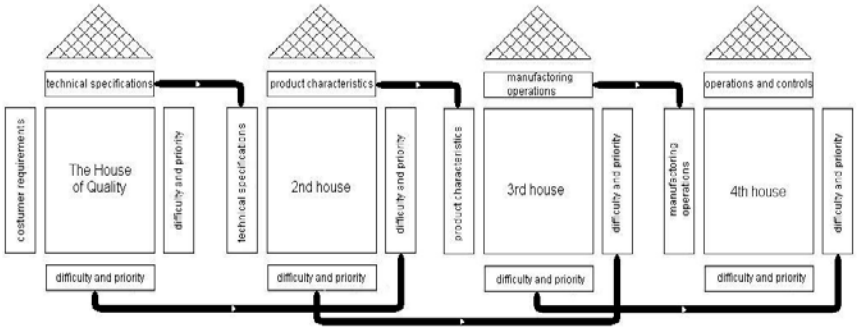

Figure 3 Interrelated houses under the house of quality (after Cohen (1995). Op cit p.14 and Shillit0 (1994). ibid)

3.4 Communication

Numerous tools for processing different aspects of development are in use nowadays. QFD can be used in addition to all the previous tools for improving the development process and help the different departments to work together more efficiently. In order to carry out their functions well all involved parties have to communicate with each other and focus on a common goal. Within the Purchasing unit, they want to go for the best materials at the best price. These materials must have exactly the properties the developers asked for. Therefore Purchasing has to understand what Manufacturing needs and product developers have to understand how this relates to costumers needs. Manufacturing also has to know if the specifications they ask for are realistic and within the budgetary range. Large errors can be caused by small misunderstandings. Having QFD in the centre helps the departments with communication and finding out how their work fits into the whole picture.[31]

In general, development cycles for products and services are rather long. Future uncertainties like major scientific developments or a change of the costumer's requirements, because of political, environmental or social rearrangements, cannot be predicted but play a major role in decision taking processes. A quantitative requirement change can easily be satisfied but in case of a qualitative requirement change a new customer requirement has to be added to the house of quality and development targets and priorities have to be adjusted. Using QFD as the centre of communication enables the organisation to react quickly to any kind of change in the customer's requirements and keep track of the development cycle.[32]

4 Example of QFD

This chapter presents an example in order to provide a better idea of how QFD works and how it was implemented in previous projects. Generally speaking, there are no limits for the application of QFD in any kind of improvement or development process. It is not only applied for product development but also for service and communication deployment. Because of the many diverse fields of application there is no 'cookbook procedure' for building the House of Quality.[33] The example comes from the automobile industry where QFD originated from. The basic concept of the House of Quality will be explained step-by-step with the help of a sub chart for the door of an automobile.

34 Dikmen I. et al (2004). Strategic use of quality fnction deployment (QFD) in the construction industry, Department of Civil Engineering, Middle East University, Ankara, p. 248
35 Hauser, J.R. and **Clausing, D.** (1988). op cit p. 5
36 op cit p. 6

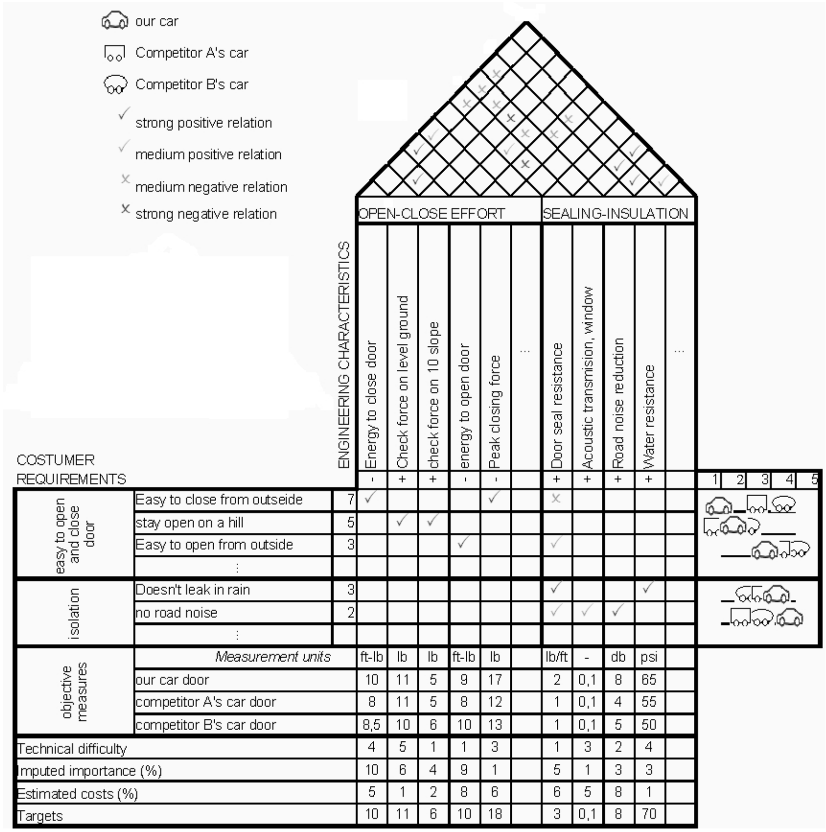

Figure 4 House of Quality for a car door (after Hauser & Clausing, (1988). Op cit p.12)

The first step is to find out the customers requirements. In this case it’s decided that the car door will be judged on the requirements “easy to close”, “stay open on a hill”, “doesn’t leak in rain” and pass of “road noise”. Generally this can be put in the groups “open-close” and “isolation”. These requirements are usually expressed in the customer’s words and are called the ‘voice of the costumer’.[34] Often this is retrieved through market surveys. Not all requirements are equally important. Their relative importance for the customer is displayed right beside the requirements in the House of Quality and sum up to a list of 100%. The customer’s voice has to be translated into technical characteristics by engineers and sales people.[35] The relationship between these engineering characteristics end the costumer requirements can be seen in the middle of Figure 4.
On the right side of the House of Quality an evaluation of competitive cars compared to our car is listed for each requirement. Analyzing this shows us opportunities for improvement and parts that are important to maintain. For the car considered advantage could be gained at the attribute “stay open on a hill” because all the cars are weak here. Looking at “no road noise” already an advantage is present. Along the top of the house one can see the technical specifications which can be measured and directly effect the customer requirements. The example in Figure 4 also displays (with + and – signs) if the technical attribute will be increased or lowered.[36]

The roof of the house gives the interrelationship between technical descriptors. A change of the gear in the car window could make the window motor smaller, but the window would go up more slowly. If the mechanism is enlarged the door will probably be more heavy, harder to open and not very anxious to stay open on a slope. Possibly one single change may influence so many other characteristics that the decision is taken to leave it like it is. At the bottom line of the chart the prioritised technical descriptors can be found, which can be seen as the target values of the design.[37 38]

Looking at the possibilities of improving the car door, this door is hardest to close compared to the competitor's car doors. As this attribute shows a high relative importance for our customer it should be enhanced. From the body of the house it can be found out which engineering characteristics are connected to the user requirement: energy to close the door, peak closing force and door seal resistance. Because of their strong positive relation with the requirement the energy to close the door and the peak closing force are the points where the maximum improvements can take place. Now the roof of the house shows which other engineering characteristics could be influenced if it is decided to change the door closing energy. Positive impact would be given on the door opening energy and the peak closing force whereas other characteristics (check force on level ground, door seals, window acoustic transmission and road noise reduction) are related negatively. Taking into account the objective measures, consumer perceptions, costs and technical difficulties the decision can be taken that the benefits of changing the energy to close the door are predominating the emerging costs. Marketing people, engineers and managers all together set a new closing target for the door which should make it the easiest to close door. This target is noted down at the bottom of the House of Quality.[39]

37 Bossert, J.L. (1991). op cit p. 7
38 Hauser, J.R. and **Clausing, D.** (1988). op cit pp. 7-8
39 op cit pp. 8-9

5 Applying QFD to the BC industry

In all building projects the realisation of the client's vision depends on how the vision is expressed, translated and communicated to the design team. The number of stakeholders, decision-making processes and the dynamic of relationships influence the way in which clients' requirements are defined. If many stakeholders participate in a project they most probably have different perceptions on the outcome of the project. This also influences the definition of the requirements. For better understanding and for solving conflicts between project requirements they should be analysed and prioritised.

In the previous chapters is pointed out what QFD is and where it comes from. Also the main problems in the BC industry are made clear. Now want to know how QFD can contribute to the BC industry. Discussions in the previous chapters have shown that QFD can offer exactly what construction projects require: a better understanding of the clients' requirements and improved communication within the whole project. QFD can be and has been applied in each of the lifecycle stages of a building and construction project in different ways. First of all QFD can be used in the inception phase, as a ranking mechanism for integrated contracts (Section 5.1) and during the design phase to guarantee optimal client satisfaction by improving the communication processes between stakeholders (Section 5.2). Section 5.3 describes the implementations of QFD after the design phase. Here differentiation can be made between application during the construction phase and during the usage phase, for improving future projects and getting a better marketing position.

5.1 Use of QFD before the design phase (inception phase)

Dikmen et al. did a literature survey on the usage of QFD in the BC industry. They found out that there are not so many applications of QFD in the BC industry and even less examples of the implementation of QFD before the design stage.[40] This is mainly because QFD is unknown to this industry. Implementation of QFD before the design stage means to use the QFD methodology before any design is chosen. The rare application of QFD in this stage is used for the assessment of integrated contracts, like Design and Build (DB) contracts.[41]

By evaluating an integrated contract, clients have to select a firm. To do this they need to be informed about the quality performance of the bid of the potential contractor. When rating an integrated contract mostly the Economically Most Advantageous Tender (EMAT) award mechanism is used. It wouldn't be a fair competition if the contract were awarded on basis of the lowest price. The design is not fixed in detail yet, so prices cannot be compared. Therefore, a kind of award mechanism is needed that doesn't only compare prices, but also looks to the quality of the service. In that case a certain value to cost ratio can be calculated.[42]

In integrating contracts the total measured quality normally can be divided into three parts: (1) the corporate quality culture; (2) the quality of the project service; and (3) the quality of the constructed facility. Arditi and Lee describe a model that was developed to measure the total quality of a DB firm by using QFD. The first part of this model measures the effectiveness of the corporate quality culture and the quality of the service, when delivering a project by using QFD.[43] The second part describes a method to measure the quality of the constructed project. It makes use of eight building quality factors, three building performance factors and the relationships between building quality and performance factors (obtained from building users) and it measures the quality performance of the facility by using QFD. A total quality performance index is generated by combining the quality performance at the corporate, project and product levels. The service quality factors are ranked relative to construction owners' needs and to expectations by means of a survey administered to construction owners. The relationships between service quality factors and quality system requirements are integrated into a House of Quality. The developed tool can be used by clients to rank DB firms relative to corporate service quality.[44]

5.2 Use of QFD during the design phase

In most of the literature examples QFD is applied during the design stage of a project. This phase is especially important for gathering all the customer's requirements, by means of definition of quality standards through technical specifications and drawings, made in this phase.[45] The design phase itself can be divided in three consecutive parts: a concept design, a scheme design and a detailed design. Every stage is more detailed than the stage before.[46]

A quite common practice in the BC is briefing. In this method a formal statement or document is used for communicating the objectives and needs of the client to the designer. This document is called brief and contains the translation of the cli-

40 Dikmen I. et al (2004). op cit p. 1
41 Arditi, D. and **Lee, D.** (2002). Assessing the corporate service quality performance of design-build contractors using Quality Function Deployment, Construction Management and Economics 2003, 21, p. 175
42 Dreschler, M. (2009). op cit p. 81
43 Arditi, D. and **Lee, D.** (2002). ibid
44 op cit p. 176
45 Dikmen I. et al (2004). op cit p.247
46 Kamara, J.M. and **Anumba, C.J.** (1999). Op cit p. 9

ents needs into technical specifications for design purposes. Usually the briefing process starts at the inception. Together with the following stages of the project the brief is developed up to the scheme design. In the past a lot of problems occurred with this method, because of the absence of a formal structured procedure in the evolution of the brief. The ineffective horizontal integration within each stage of the project and the inadequate information technology support made it difficult to monitor changes of requirements.[47]

In current briefing practice often the solution is used to specify the problem, even before the problem is understood well completely. This might tune the client in favour of the suggested solution, rather than an objective analysis of his needs. Therefore Kamara et al developed the framework of concurrent life-cycle design (CLCD), which has the philosophy that fully understanding clients' needs is necessary for developing an adequate solution.[48] This framework is based on QFD and uses the method of the client requirement processing model (CRPM). Its purpose is to formalize the methodology for processing client requirements for all project and client types in construction. The three main stages of the model are 'definition of the requirements', 'analyzing the requirements' and 'translating the requirements'. QFD is used as a method in the last stage to translate the requirements into solution neutral specifications.[49]

5.3 Use of QFD after the design phase

The use of QFD after the design stage is not very common yet. Not many examples can be found in the literature, but it seems to have a great potential if we take into account the characteristics of the BC industry. First it is explained how it could be useful in the construction phase and secondly how it could be of value after the project is completed (e.g. when it is in use).

In the literature an interesting example of the use of QFD during construction for the surveillance of works can be found. It can be seen in the Dutch BC industry, that clients (or representatives) in practice try to save more and more on the surveillance of works. This leads to a lot of criticism, because it affects the quality of execution. After all, especially in a market under pressure, the surveillance of work is one of the most important jobs for securing the quality demanded by the clients. Furusaka et al introduce a newly developed computer aided decision-making supporting system, which guarantees the assurance of the quality while mitigating the surveillance of work.[50] It is called Revised Quality Function Deployment (R-QFD), turns out to be a modified type of QFD and seems to be quite effective in practice.

In addition, QFD can be used after the construction phase, i.e. in the phase when the facility is in use. As mentioned before, the current market is very competitive and stakeholders are looking for ways to improve their place in this market. QFD can be used as a method to get a clear voice of the customer and to make comparison between different competitors, relating to this clients needs. So QFD can be used as a decision-making aid during the marketing phase. This can become of even more value taking into account the trend for a bottom-up supply-driven market with an increased level of standardisation. Producers (suppliers) establish their products to the market and look for ways to make them better. Product innovation is a hot issue here. Dikmen et al specify the goals of QFD during marketing as follows:[51]

47 ibid
48 ibid
49 op cit pp. 9-11
50 **Furusaka S.** et al (2000). Application of revised Quality Function Development to building construction project, SCIX, Japan
51 **Dikmen I.** et al (2004). op cit p.246

- Determination of a marketing strategy by identification of the expectations of the clients/end-users. The strengths and weaknesses of the design (product) can be compared with those of other competitors.
- Using the outcomes of the QFD-survey to facilitate decision-making in forthcoming projects.
- Formulation of a systematic procedure to guide future decision makers in all stages of the value chain of a construction project including feasibility analysis and design in such a way that the company can create a competitive advantage in their market by quality differentiation.

6 Conclusions

This paper has discussed some of the problems the current BC industry deals with. A major concern is the high level of distrust of clients towards the producers, caused by disappointments due to the exceeding costs and not fulfilling the client's wishes in an optimal way. On the other hand producers are dealing with major problems because they have to work in a very competitive market with low profit margins. In the traditional system they can only compete on price and not on value. Another big problem is the high rate of communication errors within the whole project cycle of BC projects. Because of the aforementioned issues a major change has to be made in the BC industry's way of thinking and working. The cost-driven approach as we have it today has to be shifted to a value-driven approach where the needs of future clients can be taken into account at early stages of a construction project. Unsatisfying results and the need for changes, after a project is finished, can be reduced when more effort is put into 'understanding what the client really wants' and 'enhanced communication among different project stages'.

QFD seems to offer exactly what is needed for the necessary change in the BC industry. Regardless to the limitations of this method, there are a lot of possibilities and advantages for the implementation of QFD in the BC industry and even recommendations for further research and developments could be found.

6.1 Advantages

In this section the focus lies on the question why QFD can be of value for the BC industry and its strengths and opportunities are discussed.

Strengths

- QFD helps to define all the needs of the client in a structured, complete and precise way. The QFD-methodology provides a systematic way to collect and identify all the client's wishes in an early stage of the design. If executed well this guarantees an optimal design. QFD also helps to translate the client's wishes into design parameters.
- QFD leads to a better communication throughout the project. It ensures consistency between the design phase and the construction phase because it provides an overview over the whole project and enables designers as well as constructors to see each other's dependency (2.3). Hereby the problems of the current situation (a lack of integration between the parties which leads to problems due to constructability of the design, delays trough incomplete designs, rework, etc.) can be solved.

- QFD helps to reduce development time and prevents uncertainty through early identification of the client's wishes. Because design teams know exactly all the client wants from the beginning, they reduce the cycle time and less redesign is required. During the construction phase an adapted type of QFD can be used for the surveillance of the work. It guarantees the quality assurance while mitigating the surveillance.

Opportunities

- QFD can be used as a ranking mechanism in the tender stage of integrated contracts. It ensures that the contract with the best value/cost performance will be chosen in a legal way.
- QFD can be used for product development and as a marketing tool. This is very important for suppliers in a bottom-up supply driven market. Producers (suppliers) put their product in the market and look for ways to make it better. QFD perfectly facilitates continuous product improvement with emphasis on learning and on innovation.

6.2 Limitations

When working with QFD in the BC industry it is important to take note of the limitations of this method in order to plan in advance the necessary corrective actions. Generally, literature distinguished two classes of limitations that have been experienced in projects: Limitations due to the philosophy of QFD are called global limitations and limitations according to its practical implementation are called application-specific limitations.[53]

Global limitations

The main issue for increasing the client satisfaction in QFD is quality. Focusing on the primary issue this technique lacks in terms of connections to budgetary issues, scheduling and technology constrains of the project or other company specific limitations. The analysis is carried out as if there were unlimited resources. Furthermore, the strategic long-term objectives of the organisation are not considered in the methodology.

The development of the House of Quality is rather based on subjective judgments than on clear facts. This may lead to subjective decisions and could reduce the reliability of this method reflecting the preferences and judgment of the team responsible for the QFD implementation.

The fact that many projects in the BC industry are carried out by more than one stakeholder is a risk to the success of QFD applied before or during the design stage in such projects. Therefore QFD can rather be applied in projects where one stakeholder is responsible for every phase of the project within a DB contract, in repetitive kind of projects or in reconstruction projects.

A lack of cross-functional communication in concurrent working environments can also lead to a failure of the implementation of QFD. This method should rather be applied in companies where the whole company philosophy tends to be aware of quality issues and aspires to continuous improvement.[54]

Application-specific limitations

The poor definition of the customers' needs plays a major role in projects where

52 A detailed example of the application of QFD within the design phase of a construction project can be found in Gargione, L.Z. (1999). Using Quality Function Deployment (QFD) in the design phase of an Apartment Construction Project, University of California, Berkeley, pp. 357-364

53 **Dikmen I.** et al (2004). op cit p.252

54 ibid

55 op cit pp. 252-253
56 Nederveen van S. et al (2010). Spplier-driven integrated design, Journal of Architectural Engineering and Design Management, 6, pp. 1-13

QFD should be implemented. In most of the cases the customer is known from the beginning of the project on but the awareness about this problem is missing. In projects where the construction is built and sold afterwards even the definition of the customer is difficult and could have a significant influence on the output of the QFD. Another important limit is the fact that it takes a lot of time and human resources to build the QFD matrices. A team working on the House of Quality should consist of experts who have sufficient knowledge about QFD as well as about technical issues and quality standards.

Ahead of the limitations mentioned before there are a lot more challenges for teams working on the implementation of QFD: reducing the number of clients needs to a reasonable amount, choosing the right technical specifications and deciding on the right relations between them and finding the right design targets. All of these tempt team members to bring subjective decisions into the whole process. To prevent misunderstandings and miscalculations it would be worthwhile to computerize the process. To provide a more objective and precise approach, various quantitative methods such as analytical hierarchy process, artificial neural networks and fuzzy logic can be combined with QFD.[55]

6.3 Recommendations

One of the reasons why QFD isn't a common tool in the BC industry yet is that most stakeholders are not aware of its existence. In order to bring QFD under attention and to make it more common sense to use QFD, it would be worthwhile to educate people in this direction. If QFD is included in the BC education programmes, people will be aware of it and will use it in the future. This can be offered at the job trainings and seminars from outsiders and education at universities. It gives students a better view on the value management and teaches them some analytical skills as well.
Another practical problem could be the length of the process and the size of the matrices. Some additional time in the planning process would be necessary to deal with all the information necessary for completing the house of quality. It would be much easier if there where some QFD computer applications and therefore we recommend the development of QFD software, in order to make the process more effective and less complicated for users with less background knowledge. The software has to be exclusive for the BC industry and one of the final objectives should be its implementation in a dynamic BIM (Building Information Model).[56] To reduce general limitations the reliability of the model would be more promising if the model produces solutions that also consider cost and schedule constraints. It would be an interesting research topic to investigate how these cost and schedule constraints can be added to the QFD methodology. Overall the most important is to get a lot of experience in practice and to learn from it. A significant jump forward is expected towards the required changes within the BC industry, by spreading and improving the knowledge of the implementation of QFD in BC projects.

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