

A KNOWLEDGE CLASSIFICATION SCHEME FOR CONSTRUCTABLE DESIGNS

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SUMMARY

Quality function deployment (QFD) is a new approach to supporting constructable design decision-making. This paper proposed a Knowledge Management model for Constructable Designs with QFD (KM-CD-QFD), which is developed to facilitate the transfer QFD-relevant knowledge and information into the early design decision-making process and extend the application of conventional QFD in constructable designs. Three components of the KM-CD-QFD are described in details. The development of KM-CD-QFD is a part of an ongoing research effort to build a QFD-based intelligent decision support system for design teams to achieve an improved constructable design at the early design phase.

INTRODUCTION

The integration of construction knowledge and experience into the early design phase provides the best opportunity to improve overall project performance in the construction industry (The Constructability Task Force of CII, 1986; Hanlon and Sanvido, 1995; Fischer and Tatum, 1997). To realize this integration, it is not only essential to provide a structural and systematic way to aid the transfer and utilization of construction knowledge and experience during the early design decision-making process, but also to organize these knowledge and experience in a manageable format so that they can be inputted effectively and efficiently into the process.

Quality function deployment (QFD) is a matrix-based decision-making method that enables a design team to specify clearly the integrated requirements of designers' upstream customers, the clients, and their downstream customers, the construction professionals, and then to evaluate each proposed design alternatives systematically in terms of their impacts on meeting those requirements. QFD has the potential to aid the development of a structural and systematic method to support the process of constructable design decision-making with suitable adoption and adaptation to facilitate its implementation in construction. However, management of QFD-relevant constructability knowledge and information is complex. It involves management not only of knowledge of constructability requirements and design features, but also of knowledge of relationships between constructability requirements and design features. While several researches have been conducted to develop classification systems for constructability knowledge and information (e.g., Tatum, 1988; Hanlon and Sanvido, 1995; Fischer and Tatum, 1997), none has been done to provide a knowledge classification scheme in the QFD-based context.

OBJECTIVES

This paper describes the development of a knowledge classification scheme for constructable designs, which is the initial finding of an ongoing research to develop a QFD-based intelligent decision support system to aid constructable designs in the conceptual design stage. Practicing architects, engineers and contractors have provided inputs for the development of this system. Specific objectives of this paper include:

- To identify and classify the knowledge of constructability attributes;
- To identify and classify the knowledge of constructable design features;
- To structure and represent the knowledge of relationships between constructability attributes and constructable design features.

RELEVANT LITERATURE

Knowledge management in constructability

Researchers developed various definitions of constructability based on their commitment to conceptual assumptions and ways of studying and applying the concept. For this research, the Construction Industry Research and Information Association's (CIRIA) definition of constructability is adopted since it focuses more specifically on design-construction interface. The CIRIA (1983) defined the concept as "the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building".

Management of constructability knowledge and information is a big subject in constructability research. Four areas in this domain were identified and reviewed: knowledge classification, knowledge acquisition, knowledge representation and computerized systems for knowledge management.

Constructability knowledge and information classification systems have been developed with various emphases. In the area of construction technology, Tatum (1988) proposed a classification system for construction technology. Ioannou and Liu (1993) developed the Advanced Construction Technology System (ACTS). In the area of structural designs, Fischer and Tatum (1997) built a framework of constructability factors for preliminary design of reinforced concrete structures. Skibniewski et. al. (1997) constructed a knowledge classification space for conceptual structural design. More broadly, Hanlon and Sanvido (1995) developed a Constructability Information Model (CIM) for all project phases.

These classification systems were developed to classify and acquire constructability knowledge by different knowledge acquisition techniques. For example, O'Connor, et. al. (1986) discussed and analyzed conventional constructability improvement data collection techniques including voluntary surveys, questionnaires, interviews, preconstruction meeting notes, and final project reports. Automated knowledge acquisition techniques, for instance, the machine learning approach (Skibniewski, et. al. 1997) and the neuro-fuzzy computational approach (Yu and Skibniewski, 1999), were also used to acquire constructability knowledge.

The ways that were used to represent the acquired constructability knowledge vary significantly. The CIRIA (1983), Adams (1989), the CII of USA (1987) and the CII of Australia (CIIA, 1993) represented the general constructability knowledge as design principles and concept guidelines. Fischer and Tatum (1997) represented the constructability knowledge in the form of explicit constructability knowledge in a way suitable for input to the design process using expert system techniques while Skibniewski, et. al. (1997) represented constructability knowledge in the IF/THEN format.

Computerized systems were developed to automatically manage and process constructability knowledge and information. These systems can be grouped into three categories based on their functions, namely, using database to manage known constructability knowledge (e.g., CIIA, 1993); integrating construction knowledge and information with other automated design systems (e.g., CAD systems) and further analyzing design solutions from the executing perspective (e.g., Fischer and Tatum, 1997); and detecting potential constructability problems and then finding solutions for them (e.g., Navon, et. al. 2000).

Constructability in Singapore

Design for constructability is regarded as one of the major means of reducing the heavy reliance on unskilled foreign workers and satisfying the increasing demand of better quality in Singapore's construction industry. To facilitate the achievement of improved constructable designs in Singapore, the Building and Construction Authority (BCA) published the Buildable Design Appraisal System (BDAS) to measure the effect of design on constructability and developed the Electronic Buildable Design Appraisal System (eBDAS) to assist this assessment at the micro level. At the macro level, the BCA also promoted a good environment for the achievement of improved constructable designs through the following ways:

- encouraging design-and-build (D&B);
- advocating the use of prefabricated, modular and standardized building component;

- propagating constructability technology and skills by voluntary and mandatory education and training;
- and mostly importantly, using government intervention that stipulated a minimum constructable score which resulted from the BDAS for different categories of building project.

The BDAS employs the following equation to compute constructable scores (BCA, 2000).

$$BS = 50[(As \times Ss)] + 30[(Aw \times Sw)] + N \quad (1)$$

Where: $As = Asa / Ast$, $Aw = Awa / Awt$, As = Percentage of total floor area using a particular structural design, Ast = Total floor area which includes roof (projected area) and basement area, Asa = Floor area using the particular structural design, Aw = Percentage of total external & internal wall areas using particular wall design, Awt = Total wall area, excluding perimeter wall of the basement. All internal walls in the basement are to be considered, Awa = External & internal wall areas using particular wall design, Ss = Labor saving index for structural design, Sw = Labor saving index for external & internal wall design, N = Buildability Score for other buildable design features.

In general, the BDAS provides a reasonable quantitative method to assess the potential impact of design on constructability. The BDAS classified constructable design features into three categories: the structural system, the wall system and other constructable features (BCA, 2000). Since government regulations under the Building Control Act require building designs to have a minimum constructable score, which resulted from the BDAS, the constructability knowledge classification scheme in this study is developed based on the BDAS. Consequently, the scope of Fisher and Tatum's work (1997) is narrower than this research and the scope of Hanlon and Sanvido's work (1995) is broader than this research. The works of Tatum (1988) and Ioannou and Liu (1993) focused primarily on construction technologies although their studies overlap the constructability research to some extent.

RESEARCH METHODOLOGY

The main research tasks, as shown in Figure 1, are comparable to previous constructability research (e.g., Fischer and Tatum, 1997). To gain a general understanding of how constructability affects designs, unstructured interviews and discussions with designers, contractors and officers of the Buildability Development Section of BCA were conducted. These interview results demonstrated the need for design-relevant constructability knowledge and were used as the starting points of formulating the framework of constructability attributes and the framework of constructable design features. Then, the above-mentioned two frameworks were developed by grouping and modifying factors from literatures (e.g., Richard, 1986; Tatum, 1988; Hanlon and Sanvido, 1995; Fisher and Tatum, 1997 and BCA, 2000).

Based on the two developed frameworks, three aspects of knowledge, including knowledge of constructability attributes, knowledge of constructable design features, knowledge of relationships between constructability attributes and constructable design features, were acquired by literatures and structured interviews. Firstly, a questionnaire was designed based on knowledge from literatures (e.g., Richard, 1986; Tatum, 1988; Hanlon and Sanvido, 1995; Fisher and Tatum, 1997; and BCA, 2000). The questionnaire was organized into three parts, the architectural knowledge, the structural knowledge and the design-relevant construction knowledge. Each part included the three aspects, namely, constructability attribute knowledge, constructable design feature knowledge and the preliminary knowledge of relationships. Following, interviews with three types of experts, including registered architects (Singapore), professional engineers (Singapore) and senior contractors and subcontractors, were conducted with the questionnaire formulated. The experts were selected by peer recommendations, for instance, as soon as one expert was suggested twice (e.g., Fisher and Tatum, 1997).

After the interviews were completed, the acquired knowledge was represented as decision rules in the IF/THEN format (e.g., Skibniewski et. al. 1997). The developed decision rules were validated by asking additional experts to review and correct them (e.g., Fisher and Tatum, 1997).

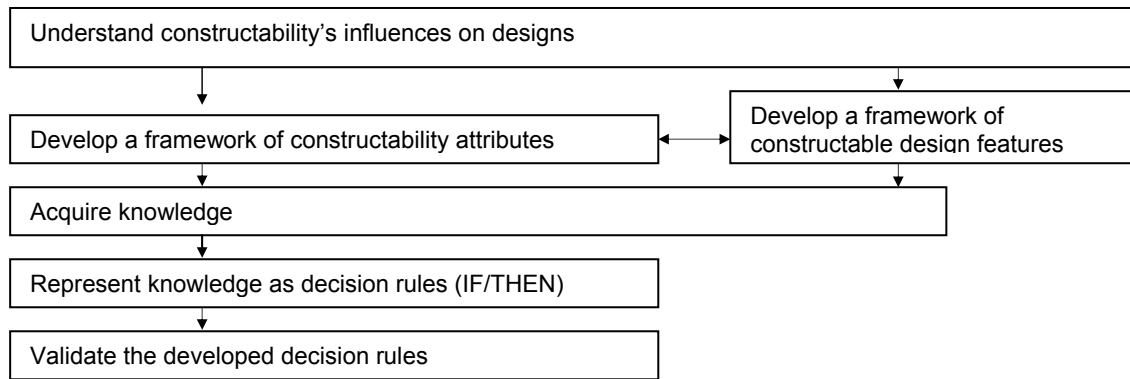


Figure 1 Main research tasks

KM-CD-QFD

A knowledge classification scheme, called Knowledge Management model for Constructable Designs with QFD (KM-CD-QFD), is constructed based on the constructability knowledge acquired in this research. The KM-CD-QFD is divided into the following three components (Figure 1):

- Knowledge Management model for Constructability Attributes (KM-ConA),
- Knowledge Management model for constructable Design Features (KM-DF),
- Knowledge Management model for relationships between Constructability Attributes and constructable Design Features (KM-ConA-DF).

KM-ConA

The journey of using QFD to gain an improved constructable design begins with early and effectively capturing and utilizing design-relevant constructability knowledge and information (Figure 2). KM-ConA, as shown in Figure 2, is built to facilitate this process. KM-ConA includes two fundamental categories, the design-relevant attributes and the construction-relevant attributes, both of which influence the design decisions on constructable design features in a particular design.

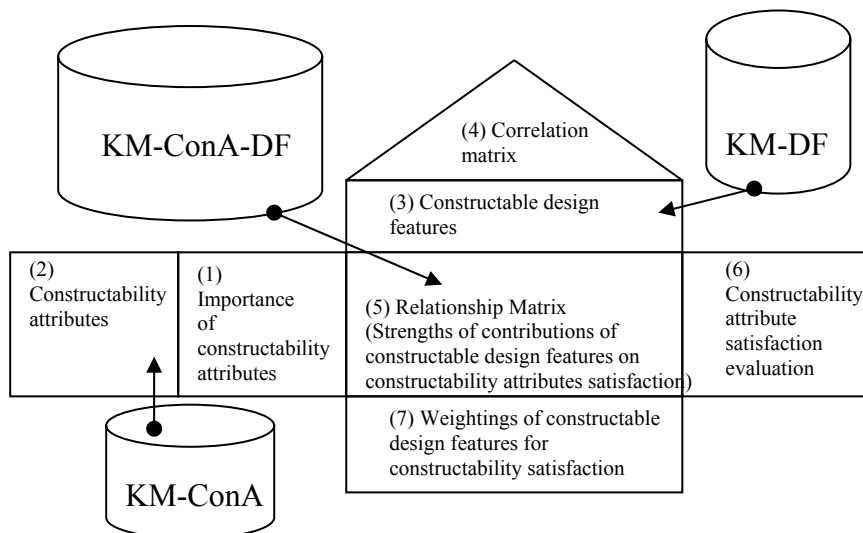


Figure 2 Components of KM-CD-QFD and their relationships with House of Quality (HOQ) of QFD

Design-relevant attributes represent the impacts of designer's concepts, including architectural concepts and structural concepts, on design for constructability. The attributes of this category are based on the work by Richard (1986). This category is further divided into two subcategories, performance and constraints. The subcategory of performance contains the criteria that are used by designers to measure the achievements of a building design against their design intention, including

the six discrete performance attributes, spatial performance, thermal performance, indoor air quality, acoustical performance, visual performance and building integrity (Richard, 1986). The subcategory of constraints includes those attributes that describe the limits of acceptability of performance attributes, including the economy, time, interaction with other systems and structural requirements. Each performance attribute or constraint attribute includes one or more parameters as shown in Figure 3. For example, the performance attribute, 'Spatial performance', contains three parameters, 'individual space layout', 'aggregating of individual space', and 'provision of conveniences and services'.

Construction-relevant attributes describe the contractors or subcontractors' requirements or concepts for design for constructability. The attributes of this category are mainly derived from the works of Hanlon and Sanvido (1995) and Fisher and Tatum (1997). The category contains the eight attributes, equipment and tools, skills, materials, time, space, utility, information, external impacts. Each attribute includes one or more parameters (Figure 3). For example, the attribute, 'equipment and tools', contains six parameters, 'acquisition cost', 'maintenance cost', 'Constraints of site conditions', 'Capability', 'Well-established market' and 'Use of advanced or innovative technologies'.

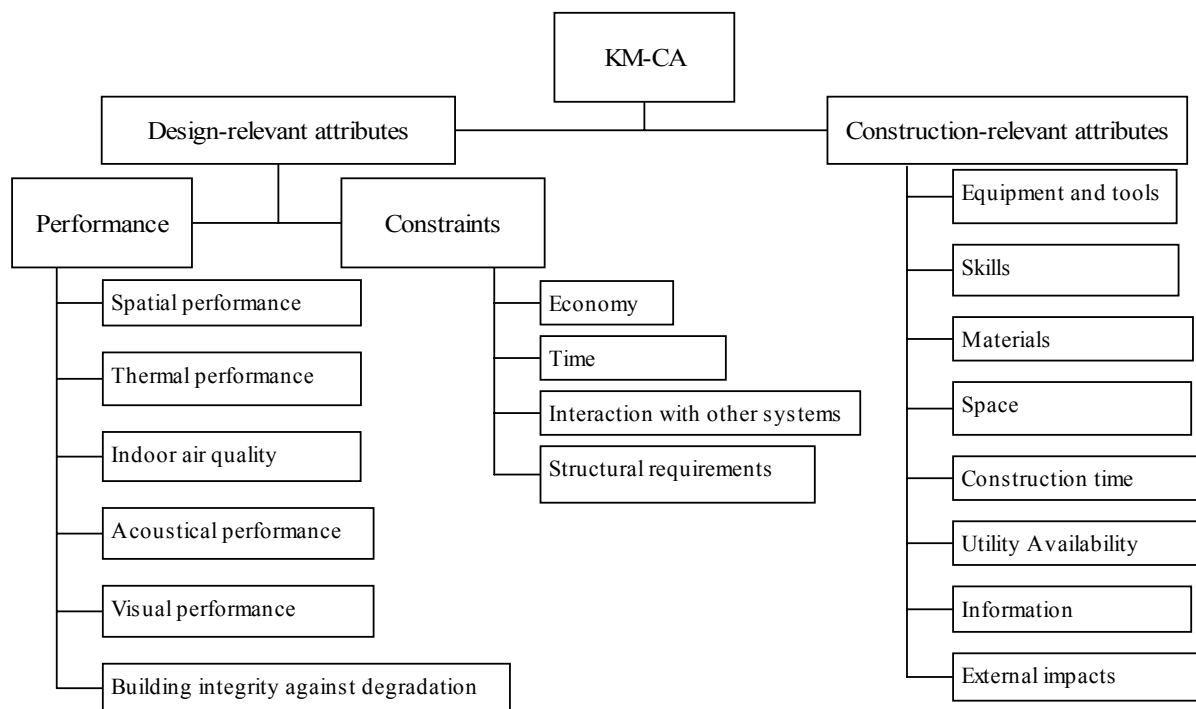


Figure 3 Categories, subcategories, attributes and parameters of KM-CA (e.g., Richard, 1986; Hanlon and Sanvido, 1995; Fisher and Tatum, 1997)

KM-DF

After constructability attributes are identified and prioritized, design features are used to satisfy their corresponding constructability attributes (Figure 4). The design features are represented as geometric forms or properties of design components in CAD drawings and specifications. KM-DF is constructed based on the work of BCA (2000) to aid in identifying and generating constructable design features. The structure of KM-DF is shown in Figure 4 and the descriptions of features in KM-DF are given in Table 1.

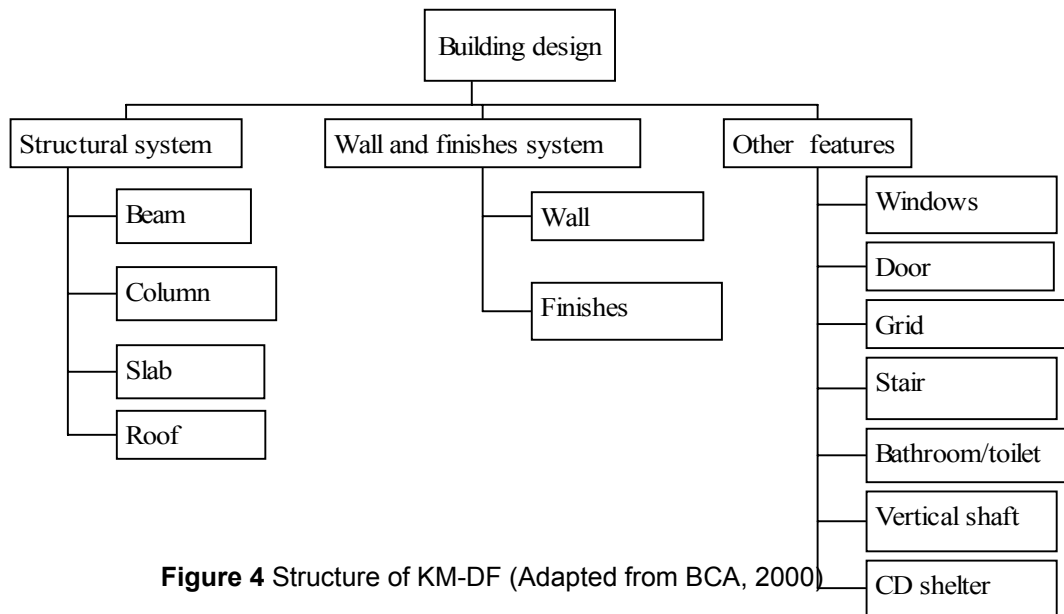


Figure 4 Structure of KM-DF (Adapted from BCA, 2000)

KM-ConA-DF

After constructable design features are generated, members of the design team need to use construction knowledge and experience to make design decisions on how much each constructable design feature impacts on its corresponding constructability attributes (Figure 2). KM-ConA-DF is developed to support the transfer of design-relevant construction knowledge. The knowledge included in KM-ConA-DF is represented as decision rules in the IF/THEN format (e.g., Skibniewski et al., 1997). The general form of a typical fuzzy rule is expressed as follows:

R_{ij} : If ($ConA_{ij}^1$ is x_{ij}^1 , and $ConA_{ij}^2$ is x_{ij}^2 , and ..., $ConA_{ij}^k$ is x_{ij}^k), Then cs_{ij} is y_{ij} .

Where, $x_{ij}^1, x_{ij}^2, \dots, x_{ij}^k$ are the linguistic variables corresponding to assessing the parameters of i^{th} constructability attribute $ConA_i$ on j^{th} constructable design feature DF_j ; $ConA_{ij}^1, ConA_{ij}^2, \dots, ConA_{ij}^k$ are the parameters of i^{th} constructability attribute $ConA_i$; cs_{ij} is the strength of contribution of i^{th} constructability attribute on j^{th} constructable design feature; y_{ij} is the linguistic variable of cs_{ij} .

For example, the decision rule that is used to reason the relationship between the constructability attribute, 'Spatial performance' and the constructable design feature, 'the type of structural system' is represented as:

If the structural system is easily adaptable to the design requirements of,

- individual space layout,
- and aggregating of individual space,
- and provision of convenience and service, of a building,

Then constructability is enhanced.

Another example of the decision rule that is used to reason the relationship between the constructability attribute, 'construction equipments and tools' and the design feature, 'the type of structural system' is represented as:

If the construction equipments and tools used to construct the type of structural system

- are highly affordable,
- and has a low maintenance cost,
- and easily fit the constraints of site conditions,
- and are capable of handling the structural elements in construction,
- and are already well-established in the market,
- and support the applications of available advanced and innovative technologies to construct,

Then constructability is enhanced.

No.	Building components	Features	Descriptions
A	Structural system	Type	The construction method of complete structural system of the building. It includes the three building components, column, beam and slab.
B	Roof	Type	The construction method of a roof.
C1	Beam	Standardization	The 3 common sizes of a beam fit the module requirement of 0.5M with the exception for steel sections.
C2	Ground beam	Location	Whether the ground beam sits on top of pilecaps.
C3	Beam cage	Prefabricated reinforcement	The usage for prefabricated reinforcement in cast-in situ beams, including prefabricated link cages done on site and prefabricated link cages from factory.
D1	Column	Standardization	The 3 common sizes of a column fit the module requirement of 0.5M with the exception for steel sections.
D2	Column	Location	Whether the column sits on top of piles.
D3	Column cage	Prefabricated reinforcement	The usage for prefabricated reinforcement in cast-in situ columns, including prefabricated link cages done on site and prefabricated link cages from factory.
D4	Column	Multi-tier precast	The usage of multi-tier concrete precast concrete column.
E1	Slab	Prefabricated reinforcement	The usage for prefabricated reinforcement in floors, including welded wire mesh (top & bottom layer) for cast-in situ floor.
E2	Slab	Non-screed floor	The usage of non-screed floor that is trowelled smooth without adding a layer of screeding.
E3	Structural floor layout	Repetition	The extent of repetition of the most repeated structural floor layout.
F	Wall and finishes system	Type	The construction method of complete wall and finishes system of the building. It includes the two building components, wall (internal and external) and finishes.
G1	Wall	Prefabricated reinforcement	The usage for prefabricated reinforcement in walls, including welded wire mesh for cast-in situ elements.
G2	Basement wall	Diaphragm wall	The usage of diaphragm wall for basement wall construction.
H	Windows	Standardization	The width and height of a window fits the module requirement of 1.0M.
I1	Door leaf opening	Standardization	The usage of standardized door leaf opening.
I2	Door structural opening	Standardization	The usage of standardized door structural opening.
J1	Grid (horizontal)	Standardization	The horizontal grid (between supports) fits the module requirement of 1M or 3M.
J2	Grid (horizontal)	Repetition	The percentage of coverage of the horizontal grid that fits the module requirement of 1M or 3M.
J3	Grid (vertical)	Standardization	The floor to floor height fits the module requirement of 0.5 M.
J4	Grid (vertical)	Repetition	The percentage of coverage of floor-to-floor heights that fits the module requirement of 0.5M.
K	Stair	Standardization /Precast	The usage of standard precast/preassembled stair sizes used.
L	Bathroom /toilet	Standardization /Prefabricated	The usage of prefabricated bathroom/toilet complete with piping/wiring that fits the module requirement of 0.5M.
M	Vertical Shafts	Standardization /Precast	The usage of vertical shafts that has the external dimensions of 850mm×850mm or 1000×1000mm.
N	CD shelter	Standardization /Precast	The usage of precast CD shelter that fits the module requirement of 0.5M.

Table 1 Descriptions of features in KM-DF (Adapted from BCA, 2000)

CONCLUSIONS

This paper proposes a Knowledge Management model for Constructable Designs with QFD (KM-CD-QFD), which is built to assist in acquiring and processing of design-relevant constructability knowledge and information to support the application of QFD in constructable designs. The model and its components are incorporated into the process of QFD implementation to aid in transferring QFD-relevant constructability knowledge and information. This incorporation facilitates the development of a

QFD-based intelligent computer tools for design teams to achieve an improved constructable design at the early design phase.

Knowledge acquisition is the major bottleneck in construction automation and in particular in constructability analysis (Skibniewski et. al., 1997). To remove this bottleneck, future researches in this area should consider the integration of automated knowledge acquisition techniques into the process of QFD implementation. The proposed KM-CD-QFD provides a starting point for such research efforts.

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