Abstract

Effective and efficient communication skills are crucial for successful projects in the construction industry. When project stakeholders' decision-making defines all requirements without exception and reaches an agreement for approval, possible waste and potential risk factors may be reduced. Design decision-making is a group rather than an individual task; thus, the final design is drawn by sharing and exchanging information with which each individual project stakeholder is interactively involved. Group decision-making enables the use of professional advice; takes advantage of greater knowledge, facts, and alternatives; and derives design plans with a high level of execution and satisfaction through sufficient opinion exchange among the stakeholders. Thus, this study proposes a novel group decision-making method based on quality function deployment (QFD) together with a communication model to define users' various requirements in a cooperative manner among stakeholders to secure reliability, understandability, and rationality in the final design plan. To verify this study, a series of communication processes related to the definition of user requested functions, modification of required functions and design feedback were presented by selecting actual cases of design development.

Keywords: collaboration; communication; group decision-making; QFD; requirement

1. Introduction

The Australian Institute of Architects and Palea, Ciobanu, & Kilyeni, (2012) have recommended that the following traits should be possessed by an architect: The ability (a) to communicate effectively, (b) to coordinate and manage complex projects, and (c) to negotiate with a client to resolve issues. During the design stages, some phases may very often be undertaken simultaneously, requiring major effort in terms of coordination and communication between the stakeholders. As a social process, a successful design process depends on a shared understanding between stakeholders. Pietroforte (1997) indicated that the function of communication is to facilitate the achievement of common goals. Further, Gabriel and Maher (2002) extended the definition of communication into the field of architecture when they stated, "Architecture is primarily about communication." Building performance can be enhanced through the implementation of effective project communications. Thus, project team communication is one of the major challenges to the successful project. Architectural design is completed through various stakeholders' proposals for solutions and the consequent decision-making, with the users' requirements as the common goal. Raj Shaida et al. contended that decision-making integrated with users' requirements enables a better decision-making process. Project teams need to clearly communicate their decision rationale to develop a consensus about design decisions. However most project teams-consisting of planners, architects, engineers, contractors, regulators, owners, operators, and other stakeholders-have a limited ability to make decisions rationally. Stakeholders' views of the built environment have grown more complex, dynamic, and uncertain. Each stakeholder also has different needs and expectations along with their own experiences, prejudices and viewpoints. These challenges require better communication methods to achieve reasonable design through interaction between user-requirements and design subjects.

Many decision making problems within organizations are a collaborative effort. Group Decision Making (GDM) has been defined in various ways, including as "a decision situation in which more than one individual is involved, each with their own
attitudes and viewpoints, recognizing the existence of a common problem and attempting to make a common decision together. GDM problems are frequently utilized in many complex real-life decision situations, such as supplier selection, supply-chain risk management, and construction value management, etc. A group can generally see a problem from various perspectives compared with an individual. Such varied perspectives create new information; and group knowledge and collaborative information are more likely to lead to better supplemented decision-making.

The purpose of this study is to develop a group decision method based on QFD and a communication model in which project stakeholders interact simultaneously with users' requirements, definitions, and design evaluations. Based on QFD, and in accordance with a project's purpose, project stakeholders can alter, modify, share, propose, approve, and provide feedback regarding users' requirements. A proposed design result from the corresponding QFD definition is then reconstructed and redesigned through a cross-review process between project stakeholders.

The redesign is executed as a feedback process when incongruity and differences between design documents and QFD conditions occur. The final design plan is executed through a joint agreement when the users' QFD requirements and design goals are completed in a reasonable way without further modification. This study focuses on a group decision method using QFD and a communication model for project stakeholders, with the intention of achieving rational design.

2. Method and Procedure
This study develops a QFD model that is connected with a building system and space program. The purpose is to define the design requirements and evaluate designs. The study also proposes a QFD communication model for project stakeholders. This study adopts the following sequence.

(1) It analyzes the purpose, focus, and method regarding group decision-making that is described in prior studies. It also analyzes essential factors based on prior studies about design communication and describes the differences between prior research and this study.

(2) It considers a basic theory on communication and QFD.
(3) It identifies the current status of communication in design tasks through a survey and investigates the factors that enhance design communication.
(4) It develops a QFD-based group-decision method to extract and systemize users' requirements.
(5) It proposes a communication model using QFD.
(6) It validates the model through a case study.
(7) It presents a conclusion and a discussion regarding future research.

3. Previous Related Work
(1) Group Decision-Making
Group decision-making (also known as collaborative decision-making) is a process that occurs when individuals collectively make a choice from the alternatives before them. It involves all participants acknowledging each other's needs and opinions, and tends toward a problem-solving approach in which as many needs and opinions as possible can be satisfied. The group participation method originates from problems of conflict because it enables various requirements to be proposed and considered.

A prior study conducted function definitions, brainstorming, design evaluation, and conflict resolution by using the group decision system in value management (VM) workshops. This study aimed to solve problems such as lack of information, shortage of time, and mutual communication that occur in VM workshops through the group decision system.

Time, cost, and quality are three major competitive objectives of every project. Moreover, a balance must be created among these objectives through optimal resource utilization. In this regard, a prior study presented a group decision-making framework to seek optimal resource utilization, considering time, cost, and quality simultaneously.

Design should meet the demands of theory, rationality, and clarity. With regard to design, the value that stakeholders take into account differs, and knowledge about goals and constraints must be reflected. A piece of research on this subject presented a rationale clarity framework (RCF) and conducted a case study. In this research, a decision-assistance methodology that seeks to clarify rationale, called multi-attribute, collaborative design, assessment, and decision integration was implemented. Then costs and benefits from each team member were assessed.

Yau (2012) proposed a multi-criteria decision-making method for high-rise residential buildings, where conflicts exist among various users because of varied interests. In addition, multiple theoretical and mathematical studies have been regularly conducted with regard to group decision-making.
(2) Communication in Design

Design communication has been investigated from two perspectives. The first is a successful key to communication and the second is a model-based system that supports communication. The following research has provided major factors that enhance design communication. Aasrum (2016) highlighted that the necessity for design communication is underestimated in the construction industry. Moreover, the amount of information required is overloaded and of this, unstructured informal communication accounts for a very large part. Thomas et al. (1998) proposed communication enhancement factors in order of importance as follows: accuracy, procedures, barriers, understanding, timeliness, and completeness. Norouzi et al. (2015) proposed integrative coordination of design information, the exact definition of users’ requirements, misunderstood requirements, mutual understanding of conflicts, and a proper timeline for information as methods to enhance design communication. Holtta proposed teamwork, personal experience, technical standards, and organizational support as four factors for design communication. In addition, the following research presented a communication model or cooperation system to support project stakeholders with design coordination. Senescu et al. (2011) developed a design process communication methodology (DPCM). DPCM focuses on improvements to multidisciplinary collaboration, process knowledge sharing, and innovation-enabling understanding of design processes. Hong S. M. analyzed information exchange among participants in design and communication processes. He proposed an integrative communication model that connects a group communication process with individual participants at the design and communication stage. Song H. proposed a cooperative design methodology between professional fields. With regard to design cooperation tools, project stakeholders can use idea cards, concept cards, requirement questionnaires, and scorecards. Shen et al. (2013) developed a communication system to review satisfaction with spatial requirement criteria by using building information modeling (BIM) in order to enhance user pre-occupancy evaluation (UPOE) at the early design stage. Design reviews are critical to the success of a construction project. Soibelman et al. (2003) discussed a way to improve design reviews by gathering experts’ experience. The authors’ design review checking system (Dr Checks) reuses direct personal experience from a database while a project team is undertaking a design review process. In many cases, stakeholders who have different perspectives and expectations about a building system need to collaborate in order to establish, clarify, and capture users’ requirements in an efficient and effective manner.

Using prior investigations, the group decision and design communication model in this current study applies the principle of concurrent engineering in order to improve the understanding of design documents, solve conflicts, and secure proper timelines. In this regard, collaborative engineering is defined by the International Journal of Collaborative Engineering as a discipline that “studies the interactive process of engineering collaboration, whereby multiple interested stakeholders resolve conflicts, bargain for individual or collective advantages, agree upon courses of action, and/or attempt to craft joint outcomes which serve their mutual interests.”

4. Theoretical Considerations

(1) Communication

The origin of communication theory is linked to the development of information theory in the early 1920s. Shannon and Weaver (1949) developed a simple linear model of communication supported by mathematical theory that is relevant to the ways in which people communicate, interpret, and disseminate information. The basic elements of communication that are the object of study within communication theory are source, sender, channel, receiver, destination, message, and feedback. Among these, a message is a concept, a piece of information, a communication, or a statement that is sent in a verbal, written, recorded, or visual form to the recipient. Thompson and McHugh (2002) provided a more advanced model, presenting an open system view of the communication process. Fig. 2. depicts the construction industry within which communication takes place. This advanced model has a simultaneous or concurrent communication process rather than a sequential process. In the model, communication is framed as a flow, a transmission of information and orders occurring within an organizational container constructed by managers.

![Fig. 2. Communication for the Construction Industry](image)

(2) QFD

Akao originally developed QFD in Japan in 1966 by combining his work on quality assurance and quality control with the function deployment approach used in value engineering. QFD is a tool for bringing the voice of the customer into the product development process from conceptual design through to manufacturing. QFD has many stages, all of which are interconnected.
to form a house of quality (HOQ) matrix. The sections constituting the HOQ matrix are as follows:

Section (I): Customer needs, requirements, and importance (WHATs),
Section (II): Technical measures (HOWs),
Section (III): Competitive evaluation,
Section (IV): Relationship matrix,
Section (V): Correlation matrix,
Section (VI): Targets’ values

5. Survey of Design Communication Awareness

In the design decision process, effective and efficient communication and cooperation among stakeholders can reduce such waste factors as design errors, reworking, design change, etc. In this study, awareness of design communication was investigated through a survey. This survey was conducted using a mobile survey method from July 30, 2016 to August 5, 2016. The survey’s participants were 37 experts in practical architecture, engineering, and construction (AEC) fields. Among the project occupants of the surveyees that were composed of managerial position (15.8%), design and ENG (39.5%), field technician (18.4%), and researcher (26.3%), design & ENG was found to be the most common. The surveyed years of the surveyees' experience was 10 to 20 years in 36.8% and more than 20 years in 21.1%. The major findings are as follows.

(1) With regard to the negative impact of design change caused by inadequate design, delayed construction (71.1%) and increased costs (76.3%) are the highest percentages (see Fig.4.).

(2) With regard to the positive influence of design change, project risk reduction (73.7%) and quality assurance that achieves rational design (71.1%) are the highest percentages (see Fig.5.).

(3) As factors that make communication difficult in the design process, limitations of time management (46%), the lack of mutual understanding of requirements and technologies (41%), and the insufficient review of integrative design (41%) are the highest percentages (see Fig.6.).

(4) The order of significance of the subjects that require communication and cooperation in the design process are time schedules (84%), interference/conflict/inconsistency issues between construction disciplines (78%), and costs (73%). See Fig.7. for more details.

(5) The order of significance of the factors that enhance communication are jointly agreed decisions (61%), explicit definitions of requirements (18%), and
According to the research about the purpose of QFD use, the ranking of the purpose was investigated to be (1) 'desire for better designs', (2) 'desire to improve customer satisfaction', (3) 'need for a cross-functional communication tool', and (4) 'reduce product cycle time'. The research result is ranked differently between the USA and Japan for reference. Therefore, the use of GD-based QFD (1) enables reduction of the time required for designing, (2) clearly defines users' requirements in the designing process, (3) allows the conduct of designing and construction based on the jointly agreed users' requirements, and (4) secures design quality with higher user satisfaction by reflecting the various views and explicit requirements of the project stakeholders.

6. QFD-based Group Decision-Making

Construction decision-making has various definitions. However, it can essentially be defined as a method to select the most appropriate option that meets predetermined criteria among various alternatives. In this regard, an analysis of whether the proposed alternative is appropriate is important, but correct decision-making cannot be achieved without reasonable selection criteria.

Since the project environment always changes and the design process is time consuming and involves various actors, the purposes are often contradictory in accordance with the perspectives of various organizations and project stakeholders. Thus, a reasonable method is required to obtain the information necessary for decision-making and appropriate decision timing. In this context, Bales and Strrodbeck suggested that in-group decision-making follows a process of plan creation, comparison, agreement, and execution. However, the order of this procedure can be changed, shortened, or extended according to the function and amount of information among all participants. Moreover, the essential difference between an individual's decision-making and group decision-making is that the latter reaches a "collective agreement" before final decision-making. Thus, the first condition for correct decision-making is to modify and change incomplete goals within a reasonably possible range through group collective intelligence.

Design goal-setting starts with the QFD definition of users' requirements. Users' requirements are classified in accordance with a building's facilities, a building's space, the system, and the subject. The original requirements are the unrefined and ambiguous goals. These must be converted into design guidelines, criteria, and technical guidelines for specification. In turn, the design guidelines and the criteria can become part of the technical characteristics and performance. At the same time, project stakeholders and the group of decision-makers propose various design solutions. Thus, in accordance with the QFD definition, a design plan is conducted and evaluated, and then, as a downstream process, the design is corrected to match the project's goal. Further, if any problems arise, the QFD definition of the goal can be subject to feedback and revised.

Fig.9 shows the user requirement transformation process with regard to QFD by describing an integrated computer-aided manufacturing definition for function modeling (IDEF0).
7. Design Communication Model

Decision-making information is repeatedly modified and improved by a project's stakeholders until the project's final goal is achieved. Modifying, stopping, and suspending incorrect decision-making is possible through communication and cooperation with project teams. Such an approach becomes an opportunity to prevent significant waste and additional design changes.

Design communication can be classified into a design's subject, participants' behavior, and media type. The subjects of communication can be summarized as problem solving, information sharing, enhanced understanding, visualization, waste removal, etc. Communication behaviors are opinions, acceptance, adjustments, refusal, feedback, etc. Media types of communication include requests for proposals (RFP), design documents, 3D models, minutes, memos, emails, specifications, material requisites, etc.

According to communication theory, a sender, receiver, message, and channel are all required if communication is to take place in the design process of the construction industry. In terms of architecture, the architect is the sender and the client is the receiver, and the proposed design is the message (information). Conversely, from the perspective of user requirement information flow, the user becomes a messenger, the designer becomes a receiver, and QFD becomes a message.

With the main communication message as QFD and design documents, the design communication frame is as follows in Fig.10. The main frame is divided into the coordination of requirements and that of technical requirements. The purpose of communication between user and design team/construction team is to coordinate requirements.

QFD is completed by the encoding process between user and designer. Moreover, some noise in the requirements can be removed by QFD transformation. A design group's decision is determined by QFD decoding, and design distortion is modified by QFD group cross evaluation. Feedback is applied in order to modify QFD or design documents. Here, a design team consists of a designer, engineer, constructor, and project manager. The detail frame of a QFD-based communication model between a user and a design team can be illustrated as Fig.11. The detailed frame is divided into the designer's development and project development and each arrow indicates communication behavior. Major communications are as follows.

1. The QFD defines and gives feedback of all requirements by project stakeholder. (P1, P2)
2. Design documents are modified to achieve the objectives of the QFD. (D2)
3. QFD requirements are changed for revision requests of design documents. (P5, P6)
4. Approved requirements dictate final design. (D3)
5. Suggest applicable solutions. (P3), etc.

Fig.10. The Main Frame of Design Communication

Fig.11. Design Communication Model Based on QFD and Design Documents
8. Pilot Studies

This case study verified the group-decision method using QFD and the possibility of its application in communication among project stakeholders. For verification of the GD (Group Decision making) based GFD model, the design development of the 00 project was chosen for the case study, the communication and the process between project stakeholders was presented on the QFD model. The first design review was carried out on the design development based on the user’s required function and design criteria pre-defined at the schematic design stage. Then, the user’s required function and the design criteria were revised based on the result of the first design review. In turn, the revision of requirements was used to revise the design development. Finally, the revision design criteria in QFD evaluated and verified the revised design. The modification communication process of review, analysis and approval on the QFD to lead the final design, may iterative and vary from project to project.

The requirements of the user from the library were defined to ensure reasonable access and space function. The designer proposed locating an English cafe toward the south and constructing a curtain wall toward the outside considering the noises that could come from the southern part, and thereby secure an open area as a space for exhibitions. Based on this concept, an SP-QFD version (1) and design (1) were completed. Next, a lack of convenience in user access was detected in the northern part on evaluating design (1), and to compensate for this, a new requirement was raised. In addition, the English cafe was expected to have lower utilization in the existing southern part when compared to the area that connected to the northern part, and thus user requirement changed. Furthermore, by reflecting on the communicated contents from the project stakeholder, SP-QFD version (2) and design (2) were completed.

The scope of this study was to propose a model and method for design communication between the project stakeholders by using the QFD. One or more case studies were not performed due to the limited space. The case study of design communication can be sufficiently verified with a computerization model in a future study.

9. Conclusions

This study developed a QFD-based group-decision method and a communication model that could be used in the early design stage and the design development stage. By conducting a survey on design communication, the definition of requirements through a joint agreement among stakeholders for a reasonable design was determined as the biggest factor for enhancing communication; requirement change and management were also identified as factors that could enable reduction in project risk and secure quality.

Through the case study of this model, it was verified that "defining requirements without omit" and "change and tracking management of requirements" could not only achieve reasonable design but also enable design function improvement. In addition, project stakeholders could evaluate the increasing and decreasing functions, and thus recognize the unsatisfactory points by taking into account the conflicts between the functions.

![Fig.12. The Case Study to Test the Communication Model with Group Decision-Making QFD](image-url)
The advantages of the communication model in this study can be summarized as follows:

1) In QFD, user requirement, design criteria, characteristics, goals, etc., can be completed by the joint-decisions because the decision-making information receives interactive feedback from the project stakeholders through their continuous participation and control.

2) Project stakeholders can present a subjective and objective evaluation of the design plan or solutions based on common generated QFD goals.

3) QFD can reduce potential design change and waste elements, as a final front-end quality plan.

There is a need to make a validity analysis of the communication model by conducting more case studies. Further studies are scheduled to develop a computer system to overcome the limitations in the time management of design work and support an integrative review of the design team.

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