New System Form Design Process Using QFD and TRIZ

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Abstract –

Current forms used in the construction site are faced with problems such as casting quality, increased labor costs and longer construction period. To solve these problems, a new system form that reflects the opinions of people who actually use it in the construction site. In this study, a new system form design process using Quality Function Deployment (QFD) and TRIZ method was proposed. It is expected that it will be possible to make an improved system form by providing a solution that combines the needs of form users and the technical elements.

Keywords –

System form; Concrete structure; Quality function deployment (QFD); TRIZ;

1 Introduction

Currently, with the buildings becoming larger and taller, reinforced concrete (RC) structures, which are advantageous in terms of usability and economics, have been increasing. Formwork is one of the most important types of reinforced concrete structure construction, accounting for 30 to 40 percent of structural construction costs and 10 percent of overall construction costs [1].

However, the form commonly used in formwork was developed approximately 40 years ago. As building construction become larger, there have been limitations such as increase of material loss rate, increase of input labor force, increase of labor cost, and defective concrete surface [2]. Therefore, it is necessary to develop a new form to solve the problem of existing forms.

Quality function deployment (QFD) is a systematic design support technique that has been used to improve the construction system [3]. The QFD method has great advantages for users because it not only translates customer requirements into technical characteristics, but also prioritizes characteristics. However, the QFD technique is accompanied by contradictory problems, and systematic analysis is needed to solve them.

A theory of creative problem solving (TRIZ) was developed to propose innovative solutions with numerous tools that enable a targeted and systematic problem-solving method [4]. Mayda and Borklu implemented a method using TRIZ to identify innovative concepts, then using QFD to meet customer's needs [5]. Hajime Yamashina et al. [5] integrated the QFD and TRIZ to analyze the customer needs by calculating the most needed technical factors and the weight of the factors. Lim et al. [3] proposed a system form design process using QFD and TRIZ. However, this was a system form design process that was limited to the table form used in skyscraper.

Therefore, this study proposed a system form design process commonly used in the construction site. The proposed system form design process reflects the needs of the customers who use the form in the field and converts them into technical characteristics. In addition, priorities of technical characteristics were determined and reflected by considering the relationship between technical characteristics.

2 Literature review

2.1 Quality function deployment

QFD is a tool used to improve product quality. It has been used successfully in assisting product developers systematically incorporate customer requirements (CRs) into engineering characteristics (ECs) to plan and manage product and process development [7]. From the interrelationships between CRs and ECs and the correlations between ECs, the main task of product planning using QFD is to determine target values of ECs to achieve higher overall customer satisfaction[8]. The House of Quality (HOQ) supports defining the relationship between CRs and ECs through comparison and analysis of data. Because of these advantages, HOQ is regarded as a QFD core element technology that reflects customer needs [9]. This is shown in Fig 1.

2.2 TRIZ

TRIZ was proposed by the Russian researcher Altshuller (1984), who was using it to solve "creative" problems, which usually have the features of paradoxical and conflicting demands [8]. TRIZ helps find contradictions and find solutions to overcome those contradictions. In Table 1, TRIZ analyzes and summarizes 39 engineering features through the contradiction matrix, and Table 2 shows 40 innovative principles corresponding to the contradiction matrix [10].

2.3 Integration of QFD and TRIZ

QFD is a good tool to convert CRs into ECs. However, it has its limits. Applying the contradiction matrix through TRIZ to solve these limitations and provide various optimal solutions. In this study, the relationship between the results of technical characteristics and the contradiction matrix of TRIZ was as shown in Fig 2. Among the technical features derived through HOQ, technical features with negative correlation were derived and converted to 39 standard features. Repetition of this mechanism gave a reasonable understanding of the contradiction of technical features and also provided a systematic solution.

Table 1. Thirty-nine TRIZ Engineering features [10]

1. Weight of moving object	21. Power
2. Weight of stationary object	22. Loss of Energy
3. Length of moving object	23. Loss of substance
4. Length of stationary object	24. Loss of Information
5. Area of moving object	25. Loss of Time
6. Area of stationary object	26. Quantity of substance/the matter
7. Volume of moving object	27. Reliability
8. Volume of stationary object	28. Measurement accuracy
9. Speed	29. Manufacturing precision
10. Force	30. External harm affects the object
11. Stress or pressure	31. Object-generated harmful factors
12. Shape	32. Ease of manufacture
13. Stability of the object's composition	33. Ease of operation
14. Strength	34. Ease of repair
15. Duration of action by a moving object	35. Adaptability or versatility
16. Duration of action by a stationary object	36. Device complexity
17. Temperature	37. Difficulty of detecting and measuring
18. Illumination intensity	38. Extent of automation
19. Use of energy by moving object	39. Productivity
20. Use of energy by stationary object	

Table 2. Forty TRIZ innovative principles [10]

1. Segmentation	21. Hurrying
2. Separation	22. Blessing in disguise
3. Local quality	23. Feedback
4. Symmetry change	24. Intermediary
5. Merge	25. Self-service
6. Multi-functionality	26. Copying
7. Nested doll	27. Cheap disposables
8. Weight compensation	28. Mechanical interaction substitution
9. Preliminary counteraction	29. Pneumatics & hydraulics
10. Preliminary action	30. Flexible shells & thin film
11. Beforehand compensation	31. Porous materials
12. Equi-potentiality	32. Optical property changes
13. The other way around	33. Homogeneity
14. Curvature increase	34. Discarding & recovering
15. Dynamic parts	35. Parameter change
16. Partial or excessive actions	36. Phase transition
17. Dimensionality change	37. Thermal expansion
18. Mechanical vibration	38. Strong oxidants
19. Periodic action	39. Inert atmosphere
20. Continuity of useful action	40. Composite materials

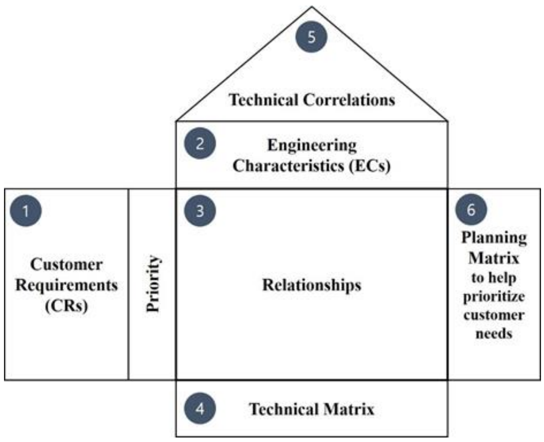


Figure 1. The House of Quality [7]

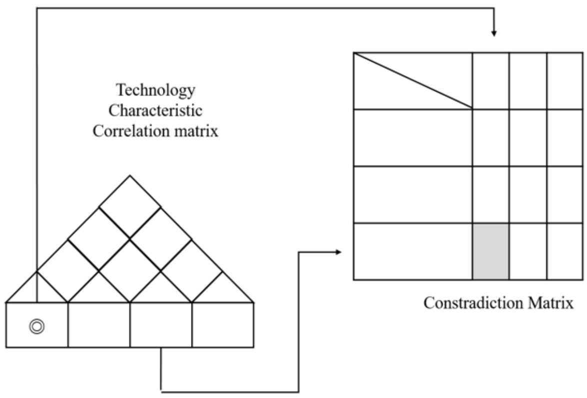


Figure 2. Mechansim of intergrating QFD and TRIZ

2.4 A case study using QFD and TRIZ

Franica et al. applied QFD and TRIZ to 3D PrinterCAD to provide innovative design methods and results in improved manufacturing processes [11].

Donnici et al. completed the QFD analysis of the hover board and suggested the solution principle to realize the hover board as urban transportation through the TRIZ method. This study demonstrated that the integration of QFD and TRIZ provides an innovative solution to the problem that has not been solved [12].

3 Proposal of Improvement System form using QFD and TRIZ

3.1 Conversion of CRs into TCs utilizing QFD

3.1.1 CRs Importance Calculation

Two interviews were conducted to derive the CRs. To collect objective CRs, the interviewees were designated as two high-rise building project directors, four formwork company presidents, and six formwork experts. The final 15 CRS were derived from the two interviews, which were as summarized in Tables 4. In order to calculate CRs significance, The IPA survey was conducted on 15 field managers in five major construction companies in Korea and 28 field workers with more than 10 years' experience. Finally, 35 surveys were completed and returned. The weighted priority of the system form CRs was determined through the IPA survey, and the overall significance related to CRs and design was classified by item. The figures from the IPA survey were translated into 100 points, which made it possible to sequence CRs importance. The three most important sequences were CR1: Easy assembly and disassembly, CR2: Reduced noise during dismantlement or assembly and disassembly, CR13: Compatible with existing formwork units. The remaining importance shown in Table4. 14 TCs was derived from the same experts and correlated them with CRs as seen in Table 3.

Table 3. Relationship between TCs and required quality

No.	Technical characteristic (TC)	Related required quality
TC1	Shape of outer frame	CR1, CR4, CR6, CR13, CR14, CR15
TC2	Weight	CR4, CR6
TC3	Size	CR1, CR4, CR13, CR14, CR15
TC4	Number of repeat uses	CR7, CR8, CR10
TC5	Shape of the inner structure	CR5, CR9, CR10
TC6	Assembly type	CR1, CR9, CR10
TC7	Installation method	CR1, CR2, CR4
TC8	Dismantlement method	CR1, CR2, CR4
TC9	Impact resistance	CR7, CR8, CR9, CR10
TC10	Allowable load	CR5, CR9
TC11	Material of panel	CR2. CR3, CR7, CR8, CR10, CR11
TC12	Material of frame	CR7, CR8, CR9, CR10
TC13	Lifting method	CR4
TC14	Structure of panel frame	CR2, CR10

3.1.2 Correlation Analysis between CRs and TCs

In this section, a correlation analysis was conducted between CRs and TCs previously classified. Correlation analysis was performed with the help of the same form developers. The degree of correlation between CRs and TCs was set to 1-low, 3-normal, 9-high. To give priority to the technical characteristics reflecting the required quality, the absolute weight was first obtained. Absolute weight is the sum of the multiplying values of the importance index and the correlation coefficient as shown in equation (1). Equation (2) divided the absolute weight for each technical characteristic into the sum of the total absolute weight by obtaining the relative weight. The priority of each technical characteristic was judged through these two equations as shown quantitatively in Table 5.

$$\text{Absolute weight} = \sum \text{Importance Index} \times \text{Correlation coefficient} \quad (1)$$

$$\text{Relative weight} = \frac{\text{Absolute weight of technical charateristic}}{\sum \text{Absolute weights of technical characteristics}} \quad (2)$$

3.2 Required TCs Contradictions

The important required technical characteristics categorized above are contradictory to each other. To solve these contradictions, the technical characteristics that reflect the requirements were summarized as follows:

1. If the external factors (TC1, TC3) are changed to simplify the assembly and disassembly, contradictions arise in compatibility (TC6, TC7) with existing forms.

Table 4. CRs-Importance Index

No.	Category	Customer Requirement	Impor-tance Index	Rank
CR1	Constructability	Easy assembly and disassembly (it fits and fastens together with reasonable ease)	91.3	1
CR2		Reduced noise during dismantlement or assembly and disassembly	87.4	2
CR3		Easy removal from concrete	76.2	8
CR4		Efficient lifting and carrying	79.6	6
CR5	Safety	Not distorted or deflected during concrete placing	56.3	15
CR6		Reduced safety accident (struck by object)	57.7	13
CR7	Durability	High repeat use with constant module size	83.2	4
CR8		Recyclable material usage	61.4	12
CR9		Durable against falling and external impacts	64.2	10
CR10		Easy maintenance and cleaning	69.9	9
CR11	Reliability	Low thermal conductivity (low temperature sensitivity)	59.1	14
CR12		High concrete surface quality	78.8	7
CR13	Conformance	Compatible (size, height, fixing method) with existing formwork units (e.g., Euro form, Aluminum form, Skydeck)	86.7	3
CR14		Hybrid (concurrent usage) usage for vertical (wall and column) and horizontal (slab) forms	63.1	11
CR15		Provide various module sizes to minimize on-site work (filler, conventional formwork)	81.9	5

2. Changes to the base metal of the material to reduce noise (TC11, TC12) contradict the form performance (TC2, TC9, TC10).
3. Reducing the weight (TC2) for efficient operation and movement causes a contradiction in form performance (TC9, TC10).
4. Changing the fastening method to the bolt assembly (TC6) for the maintenance of the form contradict the form performance (TC9, TC10).
5. Changing the material (TC11) of the panel to improve the quality of the concrete casting contradicts the reuse rate (TC4).

3.3 Proposing a new System form using TRIZ

3.3.1 Conversion to TRIZ features

In order to present ideas using TRIZ, it was necessary to relate the technical contradictions derived above to standard features. Therefore, in this section technical contradictions that deteriorated were matched during the improvement process and standard features as shown in Table 6.

3.3.2 Apply contradiction matrix of TRIZ features

Apply contradiction matrix of TRIZ features. First, apply the contradictory standard features to the contradiction matrix and extract the intersecting items in Table 7. Next it was proposed in Table 8 with the general

Table 5. A calculation matrix for absolute & relative weights between TCs and CRs

CRs \ TCs		TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8	TC9	TC 10	TC 11	TC 12	TC 13	TC 14
CR1	91	9	9	9		9	9	9	9						3
CR2	87		9					9	9			9	9		3
CR3	76								3			9			
CR4	80	3	9	3		1		3						9	
CR5	56					3					9		9		
CR6	58	1	9	3				3	3						
CR7	83				9					9		9			
CR8	61				9							9			
CR9	64		3	1		3	9		3		9		9		3
CR10	70				9	3	9			9		9	3		3
CR11	59											9	3		
CR12	78											9			
CR13	87	9		9				3	3						3
CR14	63	1		3				3	3						
CR15	82	3		1				3	3						
Absolute weight		2207	3037	2349	1931	1473	2029	2715	2898	1378	1085	4644	2258	716	1199
Relative weight		7.38	10.15	7.85	6.45	4.92	6.78	9.08	9.69	4.61	3.63	15.52	7.55	2.39	4.01
Rank		7	2	5	9	10	8	4	3	11	13	1	6	14	12

Table 6. Conversion of Contradiction into TRIZ standard features

Contradiction	Improvement objects	Converted TRIZ features	Deteriorating objects	Converted TRIZ features
1	TC1, TC3	39. Productivity	TC6 TC7	35. Adaptability
2	TC11, TC12	31. Harmful side effects	TC2 TC10	13. Stability of object
3	TC2	39. Productivity	TC9 TC10	35. Adaptability
4	TC6	34. Repairability	TC9 TC10	14. Strength
5	TC11	27. Reliability	TC4	25. Loss of time

solutions and the improved approach to the contradictory standard feature corresponding to the intersection. Our study improved the general concrete form through the principle of contradiction matrix of TRIZ.

3.3.3 Proposal of improvement form

This study associated contradictions in the technical characteristics with standard features and applied them to the contradiction matrix to provide a systematic and logical solution to form improvement. As a solution, first, the problem of compatibility and size was solved with existing form by changing integrated form into assembly type. Second, the external frame, the inner frame, and the panel were separated to satisfy the requirements of each part, and the weight was reduced, thereby improving the working environment and improving the productivity. Third, with rubber material on the corners, the problem of damage due to impact was solved. Fourth, a very thin film was applied to the panel to facilitate detachment from concrete without using form oil. Finally, forms satisfying segmentation, composite materials, prior compensation, and flexible membranes/thin films were as shown in Table 9.

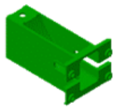
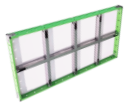
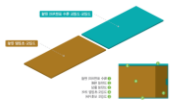
Table 7. Application of the principle of Invention of TRIZ

	2	13	14	32	25
6	–	–	–	40, 16	–
27	–	–	–	–	10, 30, 4
31	35, 22, 1, 39	–	–	–	–
34	–	2, 35	–	–	–
39	–	–	29, 28, 10, 18	–	–

Table 8. Ideal development based on general solutions of TRIZ

Contradiction	Invention principle	General solutions	Idea development
C1	1. Segmentation	Divide an object into independent parts Make an object sectional, easy to assemble/disassemble Increase the degree of fragmentation of segmentation	The form's frame could be divided into three main parts (inner, outer, and panel) to reduce the weight of forms, avoid usage of form oil, and also for ease of maintenance
C2	40. Composite materials	Change from uniform to composite (multiple) materials	Plastic-based noise-reducing materials(joint apparatus) are used
C3	40. Composite materials	Change from uniform to composite (multiple) materials	Lightweight composite material (aluminum and magnesium composite) frames could be used
C4	11. Prior compensation	Prepare emergency means beforehand to compensate for the relatively low reliability of an object	Rubber-based impact-reducing materials are used
C5	30. Flexible membranes/thin films	Use flexible shells and thin films instead of 3D structures Isolate the object from its external environment using flexible membranes	Very thin films are applied to avoid attachment of concrete

Table 9. Improvement solution according to the ideas

Idea	Improvement solution	
1. Segmentation	1	
40. Composite materials	2	
40. Composite materials	3	
11. Prior compensation	4	
30. Flexible membranes/thin films	5	

4 Conclusion

This study combined QFD and TRIZ to prioritize the technologies required by construction site system form users and to derive contradictions between their correlation and technical characteristics. It also used TRIZ contradictory metrics to provide solutions to those contradictions. The study proposed a systematic and logical system form design process that reflects the requirements of form users. The study is expected to solve the problem of compatibility with existing form by presenting the assembled form based on this system form design process. In addition, to solve the weight problem of existing form by separating external frame and panel and reducing weight. Furthermore, it will contribute to shortening the construction time, reducing the construction cost, noise and eco-friendly construction.

The systematic design process proposed in this study is expected to be applicable not only to form but also to other construction materials in construction sites. This will contribute to the reduction of the construction costs, shortening the construction time, and establishing a safe working environment.

In the future study, this process will be to make an optimal system form and conduct field test to verify form strength, concrete casting quality, noise reduction and productivity analysis. In addition, a satisfaction survey of the products produced from this study will be conducted to verify the validity of this study and conduct a complementary study of the form design process.

Acknowledgement

This research was supported by a grant (19AUDP-B106327-05) from the Architecture & Urban Development Research Program funded by the Ministry of Land, Infrastructure and Transport of the Korean Government.

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