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An Investigation of the Methods of Logicalizing the Code-Checking System for Architectural Design Review in New Taipei City

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Abstract: The New Taipei City Government developed a Code-checking System (CCS) using Building Information Modeling (BIM) technology to facilitate an architectural design review in 2014. This system was intended to solve problems caused by cognitive gaps between designer and reviewer in the design review process. Along with considering information technology, the most important issue for the system's development has been the logicalization of literal building codes. Therefore, to enhance the reliability and performance of the CCS, this study uses the Fuzzy Delphi Method (FDM) on the basis of design thinking and communication theory to investigate the semantic difference and cognitive gaps among participants in the design review process and to propose the direction of system development. Our empirical results lead us to recommend grouping multi-stage screening and weighted assisted logicalization of non-quantitative building codes to improve the operability of CCS. Furthermore, CCS should integrate the Expert Evaluation System (EES) to evaluate the design value under qualitative building codes.

Keywords: Code-checking System; architectural design review; logicalization; Fuzzy Delphi Method; building code

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1. Introduction

In the last decade, the global standard for communication tools of architectural design has gradually changed from Computer-aided Design (CAD) to the application of Building Information Modeling (BIM). The second edition of the BIM Handbook defines BIM as a modeling technology and associated tool set to produce, communicate, and analyze building models [1]. It has been found that this technology can be used during the design process to achieve the function of design communication. The recent development of the technology is still in the early stage for the building and construction industry. The tech is mostly used by designers and constructors to prevent communication barriers in the construction stage, and for constructors and users to discuss facility management in the use stage. Since 2014, the New Taipei City Government in Taiwan has progressively invested resources to develop Code-checking System (CCS) and expects to further use BIM technology to meet the communication needs of design review.

CCS requires architects to conduct BIM in accordance with the official designed templates. After transforming plans into the Industry Foundation Classes (IFC) standard information exchange format, the template is uploaded to the system engine to conduct code interpretation and detection for design review. Besides the coordination of information technology, the most important function of CCS is the logicalization of literal building codes under traditional design rules, which can help participant communicate effectively and is an accomplishment that has been recognized by experts in logicalization. Currently, the New Taipei City Government is still limited to the progress of the logicalization of building codes and can only detect preferential quantitative codes.

This study considered whether the CCS could be expected to help obtain optimized design outcomes in the review stage. Decision failure, which could arise from interference in communication in the reviewing decisions of traditional architectural design, had to be discussed in advance. Hence, this study collected the opinions of architectural experts with different knowledge and experience about design indicators in the decision-making process of architectural design, and applied communication theory to analyzing the differences in their evaluations. Using the operational features of Fuzzy Delphi Method (FDM), this study investigated the participants' differing subjective evaluations for their impact on decisions in the design communication process. This study further explored suggestions for improving the development of review decisions through using CCS as a communication tool.

2. Design Thinking and Communication

2.1. Individual Thinking to Communication

The goal of studying design thinking is to understand the thought process designers use to generate design outcomes. Initially, due to a lack of methodology, design thinking was simply regarded as a complicated behavior performed in designers' brains based on their experience. For instance, in architectural design thinking, the focus of this study, designers follow a certain thinking process based on their philosophy and technical experience—respectively, emotional and rational aspects—then use trial and error to improve their designs. The thinking process itself is a "black box". However, Rowe has pointed out that beneath the surface irregularities of designers' operational modes, common information-handling procedures can still be identified [2]. Starting with normative viewpoints of the design-thinking process, he explored designers' internal logic and decision-making processes while they were taking action, and explained and integrated the logic of decision into a theory. Rowe's study began the process of turning the black-box process of design thinking into logicalization, but still centered on investigating how designers logically generate design outcomes under "individual experience".

Following the design methods movement in the 1960s, most researchers saw design thinking as a process that solved the problem of rationally defining design [2–4]. Architectural design incorporates areas of knowledge such as functions, aesthetics, and engineering technology. If design results base design thinking only on designers' "individual experience", they would often fail because of a lack of assessment and poor problem definition. Therefore, those in the design field have gradually changed their concept of design-thinking from individual exploration to seeing design as a form of teamwork, and have investigated how to enhance team effort and decision-making quality through effective communication for the past 15 years.

Rather than exploring the logic of individual experience and unidirectional decisions in design thinking, design communication emphasizes how thinkers transmit their thinking process and results to a receiver through a medium. Among related research, Shannon and Weaver's model of communication is the most important one. It explained that a "noise source of interference" existed in the process of signal transmission and affected communication during the translation process. The process of personal encoding and decoding is correlated with communicators' range of cognition in the communication process. Communicators' knowledge, experience, and attitude will influence the process and lead to cognitive differences in communication messages. When both sides have a greater overlapping range of experience, communication is easier. Therefore, if the effects of noise source interference are decreased in the communication process through communication tools and mechanisms, communication quality can be enhanced. In applying Shannon and Weaver's communication model to the communication of architectural design, a significant source of noise interference is introduced because design thinking is built on individual experience of highly complex developments and the medium of communication is primarily images. The noise source forms not only in the pipeline stage of signal transmission, in Shannon and Weaver's model, but also in the process of message encoding and decoding [5].

Moreover, architectural design not only needs to consider the satisfaction of emotional aspects, but also to take rational factors, such as practical and technical factors, into account. In balancing the conflicting demands of the process, communication becomes doubly difficult and must occur in multiple directions instead of one-way transmission between designer and receiver. Decision-making in architectural design makes communication demands at every stage from site survey to use permits. Design communication is necessary for the designer and proprietor to reconcile their demand and programs, between the designer and reviewer in achieving building permits, and between the designer and other experts' construction management. The audience for the designers' communication process changes in different cases and procedures. Therefore, in the numerous communication processes in the decision of architectural design, minimizing interference in communication tools, medium, and channels and improving the effectiveness of the decision-making process should be investigated properly.

2.2. Communication Theory

Communication theory can be traced back to the mathematical theory of communication based on a conversion concept of transmission that was published by Shannon and Weaver in 1949. Their theory indicated the communication process deals with various concepts like information source, transmitter, noise, channel, message, receiver, information destination, encode and decode; and the noise which affect the communication flow between communicator [6]. Their schematic diagram of a communication system is shown in Figure 1; this system became the basis of later communication research. In later studies in communication theory, researchers found the process and tools of communication, information translation, and other differences would influence the communication effectiveness of the system, and could lead to communication failures in three ways. Firstly, communication is affected by "semantic differentials" and "internal feedback", as proposed by Osgood in 1954. Osgood criticized Shannon and Weaver's communication theory for being too mechanical and unidirectional. His theory includes the functions of personal conveyance and reception and takes the semantic meaning formed by signs into account. Thus, Osgood argued that interpersonal communication would be affected by an internal feedback process of personal encoding and decoding [7].

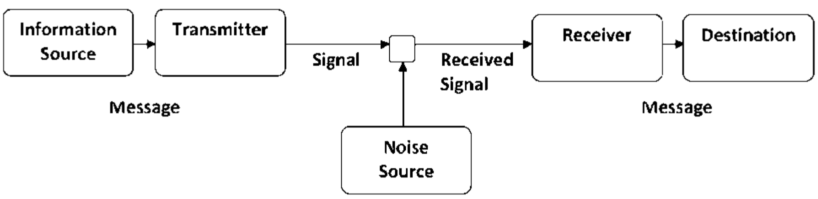


Figure 1. Schematic diagram of a general communication system by Shannon and Weaver.

In 1954, Schramm followed Osgood's lead and argued that interpersonal communication had to take the transmitter's and receiver's "fields of experience" and "cycle pattern" into consideration. According to Schramm, participants in communication had to share common experience to reach effective results. The more common experience they share, the more effective their communication, and vice versa. Further, in addition to the internal feedback process of personal encoding and decoding, Schramm explained that the feedback concept would include external feedback circulation between communicators at the same time [8]. Finally, Asch proposed a theory of the effects of group pressure for group communication. Asch argued that even if there were conflicts between group opinions and personal views, most individuals would decide to follow group opinions [9]. In summary, whatever the reasons for communication failure, such failure relates to people's understanding and usage of communication mediums.

2.3. The Concept of CCS in Taiwan

The New Taipei City Government in Taiwan aims to consistently transfer information during manual review and to improve the effectiveness of reviewing architectural design. In promoting BIM, the government has developed CCS, required architects to adopt regulatory templates in their designs using BIM in the design stage, and applied CCS in the review stage to examine BIM submitted by architects to reduce cognition gaps while reviewing design communications. According to "The report of Code-checking System for building design review in New Taipei City" [10], published by the Chinese Public Works Engineering Information Association and commissioned by the New Taipei City Government, the results, based on building code logicalization, were directly classified into three categories: pass, checked, and fail. The audit report was produced by a cloud-based system (Figure 2). The results would be used to establish communication guidelines to help subsequent manual review.

Codes	Review Items	Sub-items	Results	Test explanation	Appendix	View
A-30-04-01	Building coverage ratio, Floor area, building bulk	Building coverage ratio	Checked	252m²		
		Bulk ratio	Pass	192%		
A-30-05-01	landscape planting	Green area	Pass	232m²		
A-40-02-01	Construction cost	Construction cost	Pass	10,100,520		
A-40-03-01	Floor area for each floors	Floor area	Checked	-		
A-40-06-01	Stair height, width	Height	Pass	2.25m		
		Width	Pass	1.40m		
A-51-04-01	Arcade, Sidewalk	Minimum width 3.52m	Fail	Over building line	Contradict	

Figure 2. Example of Code-checking System (CCS) reports.

The developmental framework of the CCS is mainly divided into two parts. The first part is developing the design template, including building codes logicalization and a parameter analysis of the design template. The next step is to establish the review system engine, including testing the analysis of parameters, transferring plans to IFC, and system development of review project. These are described as follows:

2.3.1. Building Code Logicalization

Logicalization of the building codes is the first and the most crucial step of CCS. This step translates literal Building Technical Regulations (BTR) in Taiwan into information that the system can analyze through logicalization. Additionally, it analyzes whether relevant information can be obtained from the model itself or must be obtained through additional parameters. Currently, information engineering staffs are responsible for system development collaboration with design reviewers of the New Taipei City Government to conduct this logicalization step. In logicalization building codes, the regulations are initially distinguished by building use, so the template for BTR is organized according to the usage classification. In the second stage, the codes are classified into three parts—Preferential quantitative codes, partial quantitative codes, and qualitative codes—To establish the analytical logic of CCS. (Table 1).

Table 1. Classification of code interpretation.

Type	Explanation
Preferential quantitative codes	Area calculation of construction area and floor area: ratio, height of stairs, window-wall ratio, etc.
Partial quantitative codes	Walking distance, depth of courtyard, etc.
Qualitative codes	Qualitative norms of status interpretation, such as deformed land and permanent open space.

2.3.2. Design Template Development

The second step is template design and analysis. This step further logicalizes the program's processing after transforming individual statutes to literal descriptions. Because the analytic system only accepts numerical information, the template design mainly lies in integrating parameters after confirming the basis of rule interpretation. Parameters and attribute data (such as object type and fire resistance period) are built into the design template and provided as design elements (such as parking elements) and labels (such as "staircase" or "parking") for architects to use in the design phase. The handbooks are also provided for architects to download to use. Currently, the New Taipei City Government has developed and published six sets of regulatory templates for nine types of building and 24 use settings. Meanwhile, the government has also developed a template and chapter for automated review of open space-design. The template types are shown in Figure 3.

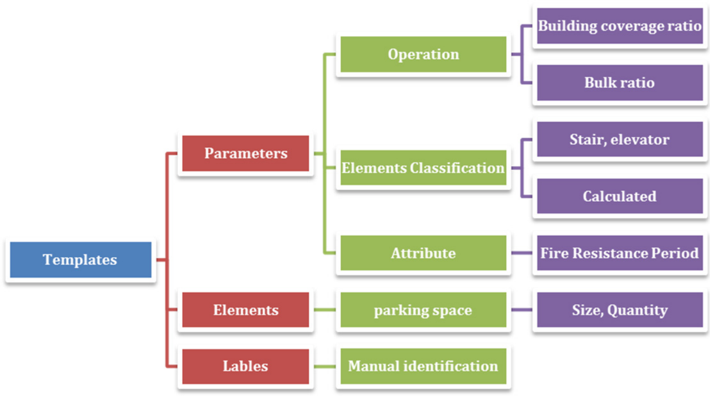
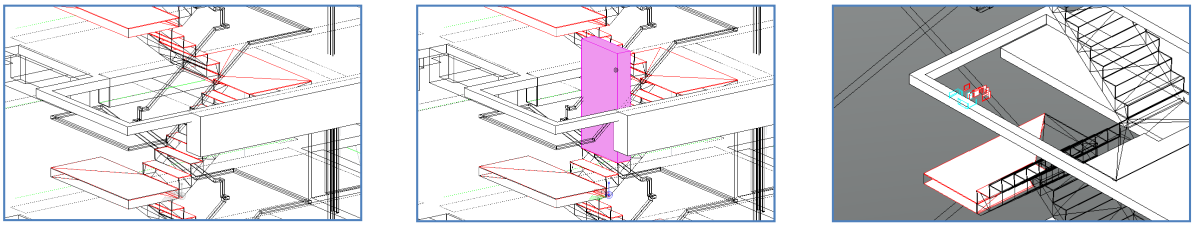


Figure 3. Classification of templates.

2.3.3. Establishing the System Engine

In logicalization building codes, along with designing development templates, a precise system reflecting the results of logical analysis must be established to detect the use of building elements. This is because, when different kinds of building use can apply to the same template file, the detection system has to conduct different interpretations. For instance, while the same template is applied for drawing stairs and platforms, different types of building use have different width requirements and the detection system has to interpret the results appropriately. Figure 4 is an example showing crash detection between IFC and the system engine, demonstrating how the system checks that the space-height of the stair is over 190 cm. The crash detection procedure has three steps:

- Getting coordinates of treads and landings in IFC (a): In this step, the engine system gets every surface of treads and landings in IFC. Then, it selects the coordinates of every surface of treads and landings.
- Crash detection (b): The system engine establishes extended line with 190 cm height to *Z*-axis and generates a virtual body of treads and landings to being crash detection.
- Crash recoding (c): Finally, the engine system records a result of crash detection. If IFC complies with the code, the system would automatically show 'pass' in review report. However, if the engine system detects any crash with IFC, the system would show 'fail' in a review report and indicate the wrong place with a figure file.



(a) (b) (c)

Figure 4. Procedure of crash detection between Industry Foundation Classes (IFC) and the system engine: (**a**) the engine system gets coordinates of treads and landings in IFC; (**b**) crash detection; (**c**) crash recording.

3. Methodology and Research Design

This study examined design-decision participants' cognitive gaps around non-quantitative codes that arose due to participants' subjective differences. We explore how to improve the logicalization of non-quantitative codes, and how to thereby enhance the reliability and effectiveness of CCS. Hence, this study is divided into two parts. First we show that because FDM utilizes multi-stage questionnaires and feedback to obtain an expert consensus, FDM clearly provides evidence of many single experts' cognitive tendencies in the process of reaching a consensus, and demonstrates the impact of group decision making on individual evaluation. In the second part, using the inspection results of FDM, we explore how to enhance the reliability of the CCS, when applied to architectural design review, through improving partial quantitative code logicalization and modifying the CCS.

3.1. Fuzzy Delphi Method

FDM evolved from the Delphi Method, which was developed for prediction and decision making by the RAND Corporation (Santa Monica, CA, USA) in 1948. The Delphi Method is a structured group-communication method and cross-field integration technique [11]. It emphasizes particular issues by asking experts to answer anonymous questionnaires in many rounds, and then leads experts to systematically develop a written consensus on these complex issues using their professional knowledge, experience, and opinions. Structured communication includes feedback based on each group member's message and knowledge, assessments of the group's judgement perspective, the probability of correction of personal views, anonymous responses, and so on. Thus, its information sources are diverse [12].

The Delphi Method has been modified several times. In order to solve the problem of semantic ambiguity, Murray, Pipino, and Gigch integrated the Fuzzy Set with the Delphi Method in 1985. Ishikawa adopted the concepts of cumulative frequency distribution and fuzzy integrals, integrated experts' responses into fuzzy numbers, proposed FDM, and opened its application in related research fields [13]. The steps for using FDM as a tool for screening assessment criteria are as follows:

1. Set Up Influential Assessment Projects and Decision-Making Groups

The first step of conducting FDM is to set up assessment projects and give a possible interval value. The minimum value is the most conservative cognitive value of the experts' quantitative score; and "the maximum" is the most optimistic cognitive value of the experts' quantitative score.

2. Collect Opinions from Different Groups

To develop statistics based on assessment project "i", it's necessary to collect every expert's evaluation of the most conservative and optimistic cognitive value, eliminate extreme values in two standard deviations, and separately calculate the minimum C_L^i, O_L^i; the geometric mean of C_M^i, O_M^i; and the maximum C_U^i, O_U^i from the remaining most conservative and optimistic cognitive values.

3. Set Up Triangular Fuzzy Numbers

Set up triangular fuzzy numbers of the most conservative and optimistic cognitive value from every calculated assessment project "i" by applying $C^i = (C^i_L, C^i_M, C^i_U)$ and $O^i = (O^i_L, O^i_M, O^i_U)$, as illustrated in Figure 5.

4. Inspect Expert Consensus

- If $C^i_U \leq O^i_L$, then the value of the importance of consensus is $G^i = (C^i_M + O^i_M)/2$.
- If $C^i_U > O^i_L$, and the gray zone of fuzzy relation $Z^i = C^i_U - O^i_L$ is less than $M^i = O^i_M - C^i_M$, which represents the interval range of optimistic cognitive mean and conservative cognitive mean, then Gi equals to the fuzzy set, which is computed by intersecting the relation between two triangular fuzzy numbers and calculating the maximum value to obtain the quantified scores.
- If $C^i_U > O^i_L$, and the gray zone of fuzzy relation $Z^i = C^i_U - O^i_L$ is more than $M^i = O^i_M - C^i_M$, which represents the interval range of optimistic cognitive mean and conservative cognitive mean, then it implies experts' inconsistent opinions and the repeated questionnaire survey need to be reconducted until Gi is obtained.

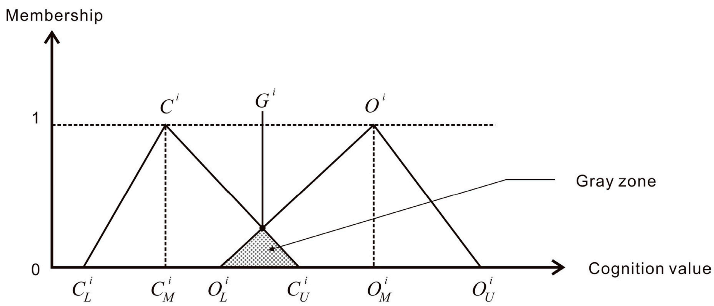


Figure 5. Schematic diagram of the Fuzzy Delphi Method threshold.

3.2. Research Design

In addition to adopting FDM for screening indicators, this study also takes seven important indicators as an upper bound to the analysis, a method often recommended by George Miller in multi-criteria decision analysis [14], adopting this as the basis for analysis after FDM has reached a consensus. Finally, using the inspection results, this study offers suggestions for improving the logicalization of partial quantitative codes and modifying the system design. This study was designed as follows.

3.2.1. Establish Indicators for Building Designs

In this study, to establish indicators for building designs, we reviewed the relevant literature on building design quality indicators [15–20] and summaries of the minutes of review committee meetings held in Taoyuan and New Taipei City in Taiwan. In the first step of FDM, the proposed important indicators include 11 indicators: Sustainable development, facilities maintenance, market strategy, building security, public interest, financial affairs, spatial function, urban form, environmental impact, building aesthetic, and intelligent technology. Some participants additionally suggested to adding an indicator of multiple satisfactions as a second step. All indicators have been shown in Table 2.

3.2.2. Grouping Exports

This study refers to the situation when governments form a review committee, and committee members are typically categorized into four groups according to the related regulations: Reviewers, scholars, architects, and developers. From each group, four experts were invited to participate in reviewing building design; subsequently, the FDM was conducted among these experts.

3.2.3. Analyze the Two-Stage Evaluation of Indicators

Experts were invited to complete an expert questionnaire regarding the evaluation of indicators. In the present study, the FDM was used to conduct a multistage questionnaire survey until a consensus is reached. At the first stage of FDM, experts presented inconsistent opinions; at the second stage, a consensus was reached between 16 experts from the four groups regarding the importance of indicators. We analyzed the assessment results to investigate the differences among the various groups of experts.

3.2.4. Feedback for Logicalization

The final part of this study reports on the effectiveness of FDM inspection results in terms of the logicalization procedure of CCS. The purpose of this study lies in enhancing the reliability and the application categories of a review system through logicalization procedure. Therefore, while conducting feedback analysis, this study puts forward principles of implementation for logicalizing the partial quantitative codes and explores the suggestion of CCS for subsequent correction of system design at the same time.

Table 2. Operational indicators.

No.	Indicators	The Operating Type Defining
1	Sustainable development	(1) Usage of green building materials. (2) Low energy consumption, and. (3) Usage of renewable energy.
2	Facilities maintenance	(1) Maintenance economy. (2) Durability of facilities and equipment. (3) Convenience of maintenance.
3	Market strategy	(1) Location (2) The situation of market supply and demand. (3) Design competitiveness.
4	Building security	(1) Adequacy of fire-fighting equipment. (2) Convenience of disaster prevention. (3) Evacuation sheltering and security operations.
5	Public interest	(1) Reserved land for public facilities. (2) Direction of public policy. (3) Regional development.
6	Financial affairs	(1) Construction costs. (2) Volume and floor effect. (3) The raise of the average floor area ratio.
7	Spatial function	(1) Spatial scales. (2) Ergonomics. (3) Barrier-free universal design.
8	Urban form	(1) Urban textures. (2) Sidewalks and open spaces. (3) Skyline and visual conflict.
9	Environmental impact	(1) Conservation of land resources. (2) Neighborhood's sunshine right. (3) Traffic impacts and pollution from construction.
10	Building aesthetic	(1) Shape of building structure. (2) Color coordination.
11	Intelligent technology	(1) Intelligent security management. (2) Intelligent energy saving. (3) Other intelligent services.
12	Multiple satisfactions	(1) Satisfaction of users' psychological value. (2) Delivery of design concept. (3) Establishment of brand image.

4. Results

4.1. Results of FDM

In the first part of this study, 16 experts were invited to review the importance of design indicators through FDM. Table 3 shows the evaluation results after 16 experts reached a consensus on 12 design indicators in two-stage FDM. To inspect whether the four different groups would have evaluation gaps due to cognitive differences for indicators in the review stage, this study chose seven indicators to analyze every stage as an index for future decision-making analysis and to make sure the results were clear. During our analysis, other indicators were treated as unimportant and discarded due to the compromise in the process of building a consensus.

Going through two-stage FDM, 16 experts reached a consensus on the importance of design indicators collectively and within each group. The important indicators, in sequence are: Spatial function, building aesthetic, building security, urban form, facilities maintenance, environmental impact, and sustainable development. However, the overall consensus and separate groups' consensus demonstrated cognitive differences in how important certain factors were perceived to be, though the experts from the four groups had already chosen seven consensus indicators for decision analysis through FDM. The two-stage evaluation results of each group and the overall evaluation results are presented in Table 4.

After determining consensus indicators through FDM, only the two-stage evaluation results of seven important indicators from the scholar's group and the final evaluation results as a whole are fully consistent. The seven indicators valued by the other three groups are respectively shown as follows:

- Reviewer's group: Environmental impact, public interest, building aesthetic, urban form, facilities maintenance, spatial function, and sustainable development.
- Architect's group: Spatial function, building security, urban form, multiple satisfactions, facilities maintenance, building aesthetic, and environmental impact.
- Developer's group: Market strategy, facilities maintenance, spatial function, building aesthetic, financial affairs, building security, and environmental impact.

Of the seven consensus indicators, only "spatial function" and "building aesthetic" are consistent in all four groups in the two-stage FDM and as the first two important indicators. Furthermore, except for the scholar's group, even though the other three groups reached an overall consensus, they still had their own preferred indicators: "Public interest" for the reviewer's group, "multiple satisfactions" for the architect's groups, and "market strategy" and "financial affairs" for the developer's group. However, these four indicators were discarded through compromise in the process of building a consensus of the overall.

Moreover, although FDM conducts expert questionnaires anonymously, the evaluation results of the previous stage are provided for participants as references to the second stage evaluation before the participants reach a consensus. Comparing the two-stage evaluation results, it was found that the operational method will lead participants to actively compromise. For instance, the architect's group evaluated "sustainable development" as the ninth ranking in the first stage, but they upgraded it to the fifth in the second stage because all other groups valued it as the one of seven most important indicators. Similarly, "market strategy" and "financial affairs" in the architect's group were separately valued as the fourth and the fifth in the first stage, and though the developer's group had the same evaluation, the others evaluated these two indicators as unimportant, which led the architect's group to adjust their evaluation and re-rank the two as the eighth and the 10th in the second stage. The same thing also happened in the developer's group, which adjusted "environmental impact" from ninth to seventh place when compromising with the other three groups' evaluations.

Table 3. A list of the overall experts' evaluation results of design indicators.

Indicator	Sustainable Development			Facilities Maintenance			Market Strategy			Building Security			Public Interest			Financial Affairs		
	Mid	**Min**	**Max**	**Mid**	**Min**	**Max**	**Mid**	**Min**	**Max**	**Mid**	**Min**	**Max**	**Mid**	**Min**	**Max**	**Mid**	**Min**	**Max**
Min	5	3	6	5	3	7	4	3	5	5	3	6	5	4	6	5	4	6
Max	9	8	9	8	7	9	9	7	10	9	8	10	9	8	10	9	7	10
Geometric Mean	6.79	5.4	7.92	7.13	5.78	8.38	6.53	5.15	7.7	7.26	5.96	8.44	6.03	4.85	7.23	6.35	5.1	7.44
Standard Deviation	1.04	1.29	0.75	0.95	1.13	0.72	1.05	0.96	1.13	1	1.25	0.98	1.12	1.05	1.18	1.11	0.84	1.17
Arithmetic Mean	6.87	5.58	7.96	7.2	5.91	8.42	6.62	5.25	7.79	7.33	6.12	8.5	6.12	4.95	7.32	6.44	5.16	7.53
G-score		6.85			7			6.19			7.09			6.56			6.43	
Rank		7			5			11			3			8			10	

Indicator	Spatial Function			Urban Form			Environmental Impact			Building Aesthetic			Intelligent Technology			Multiple Satisfactions		
	Mid	**Min**	**Max**	**Mid**	**Min**	**Max**	**Mid**	**Min**	**Max**	**Mid**	**Min**	**Max**	**Mid**	**Min**	**Max**	**Mid**	**Min**	**Max**
Min	6	5	7	5	3	6	5	3	6	6	5	7	4	2	5	5	4	6
Max	9	8	10	9	8	10	9	8	10	9	8	10	8	7	9	8	7	9
Geometric Mean	7.37	6.24	8.42	7.17	5.8	8.35	6.94	5.6	8.25	7.16	6.07	8.34	5.73	4.37	6.75	6.32	5.05	7.54
Standard Deviation	0.81	0.79	0.82	1.05	1.25	1.09	1.24	1.52	1.17	0.84	0.81	0.73	1.02	1.26	1.02	0.8	0.91	0.71
Arithmetic Mean	7.41	6.29	8.46	7.25	5.95	8.42	7.05	5.83	8.33	7.2	6.12	8.37	5.82	4.56	6.82	6.37	5.12	7.58
G-score		7.45			7.03			6.97			7.41			5.8			6.44	
Rank		1			4			6			2			12			9	

Table 4. Important indicators valued by each group and the overall consensus indicators.

Indicator		Sustainable Development		Facilities Maintenance		Market Strategy		Building Security		Public Interest		Financial Affairs	
Step		**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
Reviewer	G	7.38	7.59	7.99	8	6.45	6.74	7.41	7.47	6.43	8.31	6.01	5.96
	Rank	6	7	1	5	9	9	5	8	10	2	11	12
Scholar	G	7.57	7.12	7.71	6.63	5.88	5.64	7.77	7.74	6.74	5.69	5.64	6.18
	Rank	3	4	2	7	10	10	1	1	8	11	11	8
Architect	G	6.37	6.28	6.2	6.7	6.94	6.33	7.23	7.46	5.84	5.72	6.74	6.23
	Rank	8	9	9	5	4	8	2	2	10	11	5	10
Developer	G	5.53	6.03	7.85	7.22	7.22	7.33	8.05	6.51	4.1	5.6	7.01	6.58
	Rank	10	10	2	2	4	1	1	6	11	11	5	5
G		6.85		7		6.19		7.09		6.56		6.43	
Rank		7		5		11		3		8		10	
Indicator		**Spatial Function**		**Urban Form**		**Environmental Impact**		**Building Aesthetic**		**Intelligent Technology**		**Multiple Satisfactions**	
Step		**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
Reviewer	G	7.91	7.97	7.71	8.21	7.71	8.74	7.14	8.24	6.68	6.7	-	6.47
	Rank	2	6	3	4	3	1	7	3	8	10	0	11
Scholar	G	7.03	7.1	7.31	7.2	7.55	6.84	7.18	7.24	6.04	5.48	-	5.98
	Rank	7	5	5	3	4	6	6	2	9	12	0	9
Architect	G	7.47	7.47	6.98	7.2	6.55	6.36	6.53	6.61	5.29	4.71	-	6.71
	Rank	1	1	3	3	6	7	7	6	11	12	0	4
Developer	G	7.01	6.96	6.38	6.13	5.84	6.36	6.1	6.87	5.86	5.53	-	6.22
	Rank	3	3	6	9	9	7	7	4	8	12	0	8
G		7.45		7.03		6.97		7.41		5.8		6.44	
Rank		1		4		6		2		12		9	

To summarize, it was found that although the 12 indicators were successfully narrowed down through consensus using the two-stage FDM method for conducting decision-making analysis through expert questionnaires, the focused cognitive evaluation of each group still has significant differences, revealing the results of compromise during the consensus-building process. Finally, this study shows that the important indicators valued by each group differ according to individual experience and professional consideration. The reviewer's group demonstrated concern about public interest; the architect's group, concern about multiple satisfactions; and the developer's group, concern about market strategy and financial affairs. These indicators were excluded from the consensus indicators due to compromise in the process of building an overall consensus. The empirical results demonstrate that traditional manual review process might cause problems for the following reasons:

1. Design information and communication tools have to be built on the basis of similar cognition on both sides. Those whose work experience and professional backgrounds differ will come to communication situations with different priorities, and the intentions behind the situations are subject to change, even when consistent design specifications are the same.
2. An architectural design process mainly based on graphic thinking easily creates cognitive gaps in the process of communication encoding and decoding due to differences in participants' knowledge and field of experience. These gaps constitute the interference in communication mentioned by Schramm's "field of experience," and can result in barriers or even failures of design communication.
3. The selection of a design program is a multi-criteria decision-making problem. There is a relation between interdependence and feedback in the process of design communication. Preferences in the personal experience field will create a condition similar to Asch's concept of herd behavior, and lead to compromise in the index evaluation.

4.2. Feedback to Logicalization of CCS

The goal of the New Taipei City Government in developing CCS is to reduce the problems arising from manual review. Since the system analysis only accepts numerical information, the CCS's function, which the New Taipei City Government has finished at the present stage, is limited to preferential quantitative codes in BTR. Though the function reduces the error rate of quantitative codes, it is unable to solve the problems of partial quantification and qualitative codes further, which limits the future development of the review system. Therefore, on the basis of our FDM analysis results, this study suggests implementation modalities for logicalizing building codes and makes the following suggestions to upgrade the functionality of decision making for qualitative evaluation in CCS.

4.2.1. Use EES to Support CCS in Evaluating the Design Value under Qualitative Codes

The concept of CCS uses intelligent technology to check whether architectural design adheres to building codes. With regard to subjective values in evaluating architectural design, the system cannot yet carry out it. However, in addition to assessing compliance with quantitative codes, the review of architectural design still requires evaluation for values such as urban design, open-space design, and other cases examined by the committee. Therefore, this study put forward (2)–(4) three principles for improving the reliability of logicalizing building codes and suggested further developing EES, which can be integrated into CCS, through FDM analysis subsequent to this study. After integrating EES, CCS should be able not only to carry out a quantitative code review, but also to evaluate the indicators of review members through quantifying the indicators for reviewing work involving value evaluation. Also, the system should be able to automatically evaluate whether a given design value has obtained the consensus of all review participants or not. This way, it will be able to become part of the review decision-making system for value-based evaluation of qualitative codes.

4.2.2. Logicalizing Partial Quantification and Qualitative Norms into Quantitative Codes through Weighted Design

The biggest difference between staged quantification, qualitative codes, and preferential quantification is based on whether experts will form cognitive gaps for codes owing to their field of experience or not. These gaps are similar to experts' relative difference of degree of attention on evaluation indicators. Thus, this study suggested that adopting weighted design could respond to these relative differences and achieve the function of logicalizing design criteria into preferential quantitative codes.

4.2.3. Weight Setting has to be Based on Experts' Group Decision Making

Although weight setting can effectively logicalize partial quantitative codes into preferential quantitative codes, it was found that effective integration of professional advice and using weighting to respond to the degree of attention on consensus indicators is the key to weight setting on the basis of the FDM analysis results of the previous stage. Therefore, this study suggested that the process of logicalizing partial quantitative codes will need to include decision-making mechanisms of grouped professionals rather than reaching decisions with only information technology staff and reviewers.

4.2.4. Utilizing Multi-Stage Decision Process to Avoid Conformity Effect in Group Decision Making

Finally, the results of FDM indicated that different fields of experience in participants not only caused cognition difference, but also resulted in conformity effect during group decision making. Hence, this study suggested that the logicalization could utilize a multi-Stage decision process to avoid the conformity effect in group decision making for precisely achieving consensus.

5. Conclusions

The purpose of an architectural design review is to have an administrator confirm that building designs conform to building rules. Traditional manual review depends on the designer's and reviewer's experience for effective communication. This method does not use communication tools and often causes communication barriers owing to cognitive gaps between participants. To resolve the problem of cognitive gaps, the New Taipei City Government in Taiwan has adopted BIM technology to develop CCS for supporting a manual review.

However, CCS can only successfully check preferential quantitative codes, owing to current limitations of the code logicalization process. Thus, in order to fully understand the problems of manual review and to provide recommendations for enhancing future system development, this study invited sixteen experts in four groups from the architectural design field. FDM was conducted with these experts. After examination, inconsistencies were found in the important indicators for evaluating results among groups that have different work experience and professions. Applying communication theory, the situation confirms that though communication tools are supplied by technical design codes in the process of traditional manual review, the "fields of experience" referred to by Schramm's communication model will still become a source of noise and interference in communication.

Additionally, conformity will emerge and cause valued important indicators to be overlooked in the process of obtaining a consensus. Hence, while the current initial stage of CCS can reduce human errors and integrate most cognitive information, if it is going to be used to further replace manual review, problems of development technology, code integration, and professional recognition have to be overcome.

On the basis of the empirical results of this study, we specifically suggest that in addition to continuously maintaining accurate logicalization of quantitative codes to enhance the system's reliability, subsequent development of CCS should follow three principles to promote logicalization of partial quantitative code. First, users should logicalize staged quantification and qualitative codes through weighted design. Second, weight setting has to be based on experts' group decision making.

Third, the decision-making problem of herd behavior in a single procedure should be solved through multi-stage group consulting procedures. Finally, this study also suggested that CCS can implement the FDM concepts used in this study to integrate EES and develop a decision-making system with the additional function of value evaluation for architectural design.

Later studies will further adopt Analytic Hierarchy Process and in-depth interviews to explore similarities and differences between external and internal groups, to compare the effectiveness of traditional decision making through expert meetings to the effectiveness of multi-stage group consulting procedures, and to better understand the relation between group decision making and weight setting. It is hoped that this and subsequent studies will allow the evaluation process, which has reached a high degree of consensus, to be completed as the basis for developing EES.

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