FACTORS NEEDED FOR THE DEVELOPMENT OF A CONSTRUCTABILITY ASSESSMENT MODEL FOR BUILDING RENOVATION AND EXTENSION IN KOREA

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It is important to measure and evaluate, and thus control, constructability in construction at an early stage. This is especially important in renovation projects because it may affect various aspects such as the remaining structures, adjacent buildings, and those remaining in operation. In the construction industry, constructability studies have been carried out pertaining to deriving, quantifying, and evaluating constructability factors. However, most of these studies are focused on new building construction. As a result, there is no tool available for assessing constructability in renovation projects. Therefore, the purpose of this study is to analyse factors affecting renovation constructability to enable quantitative assessment. A literature review and expert interviews were conducted to derive the factors, and factor analysis was performed to assess constructability. Twenty-seven key factors were derived and the factors that should be considered when evaluating constructability of building renovation have been summarised. In the future, renovation constructability assessment models can be developed using these factors. Furthermore, the quantitative evaluation of renovation design is possible if a comprehensive evaluation of the constructability index, project cost, and time is integrated into one package.

Keywords: building renovation, constructability assessment model

INTRODUCTION

Across the world, the number of ageing buildings is increasing rapidly. As the number of these buildings increases, the interest and investment in renovation is also increasing (Ma *et al*., 2012). As a result, many studies have been conducted to manage old buildings effectively. Renovation is considered a maintenance plan for old buildings; it plays an important role in the maintenance of existing buildings and in saving energy, increasing structural safety and improving the residential environment (Baek and Park, 2012). In addition, renovation projects affect profitability by raising the value of existing buildings, and, as a result, owners of renovation projects are interested in making profits (Cho and Yoon, 2016). In Korea,

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owners who are also union members form groups to drive the renovation of old apartments and these projects are promoted based on their collective opinions.

Apartment house renovation has a variety of alternatives (ALTs) at the design stage, and therefore the optimal design selection process is inevitably conducted jointly (Yoon, Jung and Yu, 2017). When choosing a renovation design, the clients (owners) consider the range of improvement given the limited space and resources (Rosenfeld and Shohet, 1999). This notwithstanding, construction costs and constructability are important factors for the contractor (the construction company). In other words, the client evaluates the design from the viewpoint of profitability, while the contractor evaluates the design in terms of the construction cost and constructability. A conflict of interest is a major risk factor in renovation projects.

In renovation projects, design evaluation is carried out at the design stage. However, the evaluation of constructability during this design evaluation process is not sufficiently performed (Yun, 2015). The renovation design is taken forward based on profitability alone, without accounting for construction efficiency. This can eventually lead to an increase in construction time and project costs. Constructability evaluation should be performed at the schematic design stage to ensure that construction knowledge is integrated into the design (Albattah, Goodrum and Taylor, 2015; Dai, Goodrum and Maloney, 2009) and to ensure that an appropriate agreement between the client and the contractor. Constructability analysis is conducted to reduce the construction period, construction cost, and, at the same time, improve quality. Therefore, there is a substantial amount of literature on various facets of constructability analysis and evaluation.

However, most of the constructability research has been limited to newly constructed buildings. Furthermore, constructability analysis focuses less on quantitative analysis than on the qualitative approach (Wong, 2007). Quantitative assessment allows objective evaluation based on attribute values (Lam, Wong and Chan, 2006). In Singapore, a buildable design appraisal system (BDAS) has been used to quantify the constructability (buildability) score for measuring the performance of construction projects since 2001. This system is employed as the measurement methodology for various types of buildings (residential, commercial, industrial school, institutional, and others), and is therefore important because it can be universally applied. However, there is no provision for renovation.

In view of the rapid increase in the number of old buildings and the important role of maintenance in the industry, an index of constructability for renovation is needed. Wong (2007) created an evaluation model for the constructability of various types of new buildings in Hong Kong, which is similar to the BDAS. As in the case of BDAS, however, there is no provision for renovation. In other words, there is a lack of provision for major types of work that are important in renovation, such as foundation reinforcement work. BDAS (2017) and Wong (2007) are limited because, although they are designed to be applied to various types of buildings, renovation is excluded from consideration. In other words, the evaluation factors do not comprehensively reflect the characteristics of all building types.

In addition, at the design stage, constructability evaluation factors are closely related to risk factors; however, development takes place without reflecting on the risk factors. Therefore, a new evaluation index is needed (Table 1). Some studies have been conducted on some aspects of renovation constructability analysis, but they are limited to the qualitative evaluation of the constructability checklist. Therefore, the objective of this research is to derive key factors to develop a quantitative evaluation system for renovation projects. Furthermore, this research addresses underground expansion construction, which is the most important part of a renovation project. This is because it is most difficult and costly to expand underground space while maintaining the existing structure. It also affects the foundation reinforcement and upper expansion works. In addition, it addresses the key factors including the remaining types of work.

Table 1: Problem statement and research purpose

Division	Contents
Limitations of Constructability Assessment Model(CAM)	The measurement target is for almost all types of buildings
	No evaluation index for demolition or reinforcement, which is a renovation characteristic
	Not considering risk factor in design evaluation
Response to the limitations of previous CAM	Identifying factors and process development for quantitative constructability evaluation of renovation project
	Deriving risk factor in building renovation

METHODOLOGY

This research was conducted in two stages. In the first stage, a literature review was carried out to draw out the problem statement and constructability factors. Constructability factors were derived by analysing the prior literature related to constructability evaluation and expert surveys. In the second stage, the constructability factors were evaluated by experts in the renovation field. From the expert interviews, 27 factors were selected for the renovation constructability assessment model (RCAM) (Table 2).

Table 2: Summary of the RCAM factor selection procedures

Phase	Objective	Analysis	Summary of analysis		
			Subject	Method	Output
I	To prepare RCAM factor pool	Qualitative	Prior research and cases	Literature Survey and expert survey	Candidate factor list (40 factors)
II	To find applicable factors	Qualitative	Selected factors list (40 factors)	Expert interviews	Applicable for RCAM factor list (27 factors)

LITERATURE REVIEW

Building Renovation and Extension

Renovation can be defined as enhancing the value of buildings that are degraded in physical, economic, and environmental value compared to the value at the time of construction (Yoon and Yu, 2017). Such renovations, including horizontal and vertical expansion, are limited to the extent permitted by law (Figure 1).

Constructability Analysis

Prior to deriving constructability factors for renovation, it is necessary to analyse the constructability factors of previous studies. Many constructability studies summarise the critical factors, but these factors are focused on new buildings. Therefore, factors related to renovation should be selected out of these and then applied. This research summarises the literature review of constructability factors related to building (Table 3).

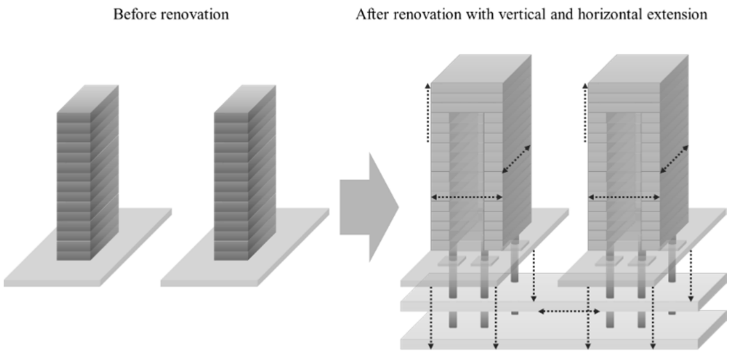

Figure 1: The concept of building renovation and extension

Table 3: Constructability literature review

No	Reference	Scope of Application	Constructability Attribute (Number)	Constructability Attribute (Contents)	Measurement Method	Country
1	BCA (2017)	All building types	Not specified	Structural system, projected area, basement area, wall system, labour saving index, designs/features such as standard columns and beams, prefabricated mechanical electrical and plumbing (MEP), high strength concrete, etc.	Quantitative analysis (calculating buildability score)	Singapore
2	Lam and Wong (2011)	All building types	9 buildability factors	Economic use of contractor's resources, design requirements to be easily visualised and coordinated by site staff, development and adoption of alternative construction details, standardisation and repetition, prefabricated and onsite works, simplification, Minimising the impact of weather conditions, safe construction sequence	Quantitative analysis The analytic hierarchy process (AHP), survey, interview)	Hong Kong
3	Wong (2007)	All building types	6 elements, 47 attributes building system	5 structural frames, 4 roofs, 5 slabs, 5 envelopes, internal walls, 5 finishing systems, 7 building service aspects, 7 building features, 5 site specific factors	Quantitative analysis (calculating buildability score)	Hong Kong
4	Yang *et al*., (2003)	Not specified	Buildable component from clients, designers, contractor's requirement	Structural systems, wall systems, refuse chute, bath room, balcony	Quantitative analysis (House of quality and fuzzy theory)	Not specified
5	Zolfagharian and Irizarry (2017)	Commercial buildings	10 elements, 50 attributes building system	11 structural frame types, 7 slab types, 10 roof types, 11 external wall types, 9 internal wall types, 4 staircase types	Quantitative analysis (AHP, survey, interview)	United States

It is necessary to add or delete factors considering the renovation characteristics (such as existing structure condition and environmental factors). Furthermore, as a quantitative model for design evaluation, the BDAS in Singapore can be actively referred to as a precedent study. The BDAS was applied to improve constructability in Singapore (Lam *et al*., 2006). The following is the concept of the BDAS evaluation model.

[Buildable design score of superstructure or basement = Buildable design score of structural system + Buildable design score of wall system + Buildable design score of design for manufacturing and assembly technologies]

Each score is expressed as the product of the labour saving index and floor area ratio, and the product of the labour productivity index and wall area ratio. The system consists of a hierarchy model that is made up of structural systems, roof systems, wall systems, other constructability factors, bonus points and so on, similar to the BDAS. In this research, it is necessary to create an evaluation system by deriving factors that reflect the existing structured model and the required renovation characteristics. For example, this research presents the factors of underground space expansion, which is the most important and critical type of work. Underground space expansion has the largest impact in terms of cost and time, because it greatly affects the superstructure

Factors Affecting Constructability

Types of Underground Space Expansion

The expansion of the underground space of an apartment can be divided into horizontal expansion, vertical expansion, and the construction of a house separate from the main building (annex) (Figure 2). The constructability varies greatly depending on each type. This is because the selection of the construction method, the type of foundation reinforcement, and the construction process are determined according to the underground expansion type.

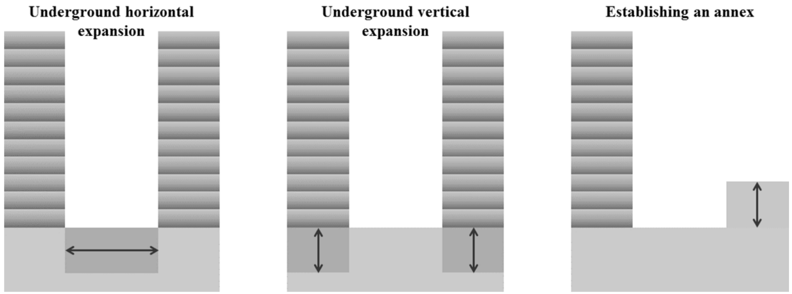

Figure 2: Types of underground space expansion

Constructability Factors When Expanding Underground Space

Expert interviews were conducted with seven renovation experts. The main objective of the expert interview was to derive the factors affecting the constructability in underground expansion. In fact, as there are numerous factors affecting constructability in renovation projects, we tried to derive the critical factors for the constructability assessment model.

Table 4: Overview of expert interview

Division	Description
Objective	To identify constructability factors when expanding underground space in renovation
Target	Five project managers of construction companies experienced in renovation projects
	(3 construction managers, 1 foundation reinforcement work, 1 demolition work)
	Two professionals associated with renovation projects (professors of construction management)
Method	Questionnaires through meetings, and question and answers addressed online and via the telephone

The process of extracting constructability factors of underground space expansion work is derived from the decision-making process that determines the type of underground space expansion and construction method. It also includes predictable risk factors in the process. The decision process of underground expansion is as follows (Figure 3).

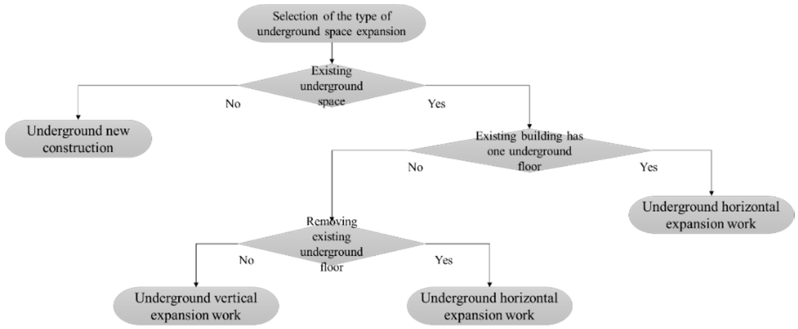

Figure 3: Decision flow in underground expansion

Based on the above figure, a total of five key factors were derived: (1) underground floors, (2) location and spacing of adjacent buildings, (3) scale of existing building, (4) demolition range and reinforcement method, and (5) selection of the construction method considering the constructability when reinforcing the foundation by extension.

Key factors affecting constructability in renovation projects

On the basis of the building renovation and extension study, the renovation constructability study, and the expert interviews, 27 constructability key factors were derived: 15 structural factors, 2 wall factors, 5 architectural factors, and 5 other factors selected as key constructability factors of the renovation work (Table 5).

Table 5: Key factors affecting constructability in renovation projects

Level 1	Level 2	Level 3	Reference
Structural systems	Existing building structural systems	Consistency of drawings with existing buildings	
		Structural safety index of existing buildings	
		Site accessibility of manpower, equipment, and materials in accordance with existing buildings	Lam and Wong (2011)
		Existing building slope	
		Structural reinforcement scope	
		Selection of materials and equipment for demolition and repair work	Yun (2015); Lam and Wong (2011)
		Selection of the construction method considering the constructability when reinforcing the foundation by extension	Yun (2015)
	Underground space expansion	The number of underground floors	
		Location and spacing of adjacent buildings	
		Scale of existing buildings	
		Demolition range and reinforcement method	Yun (2015)
		Selection of the construction method considering the constructability when reinforcing the foundation by extension	
	Etc.	Prefabricated MEP	Wong (2007)
		Standardisation and repetition	Lam and Wong (2011)
		High-strength concrete application	BCA (2017)
Wall system	External	Cladding system application	Zolfagharian and Irizarry (2017)
	Internal	Dry method application	
Architectural system		Workspace optimisation in limited space	BCA (2017)
		Technical provisions and clarification of specifications for renovation projects	Yun (2015)
		Moving ground parking space underground	
		Internal and external specialisation plans	
		Increase the number of bays (e.g. 2bay → 3bay)	
Etc.		Requirements of the client	
		Constraint (noise, vibration, and environmental pollution such as dust)	
		Accuracy of site survey for existing buildings	
		Underground facility status	
		Complaints from the neighbourhood	

Methodology to Develop Renovation Constructability Assessment Model (RCAM)

The goal of the analysis of constructability factors is to develop a constructability evaluation model. Through this, we can find optimised design alternatives by evaluating each of the design alternatives. The following analysis methodology can be applied on the basis of the constructability factors (Figure 4). After the factor finding, factor weighting is performed to derive the constructability index (CI). Using CI and expert evaluation, the score of the design (ALT 1, 2, 3…N) can be derived as shown in Figure 5. From the sum of each constructability score, design ALTs are compared.

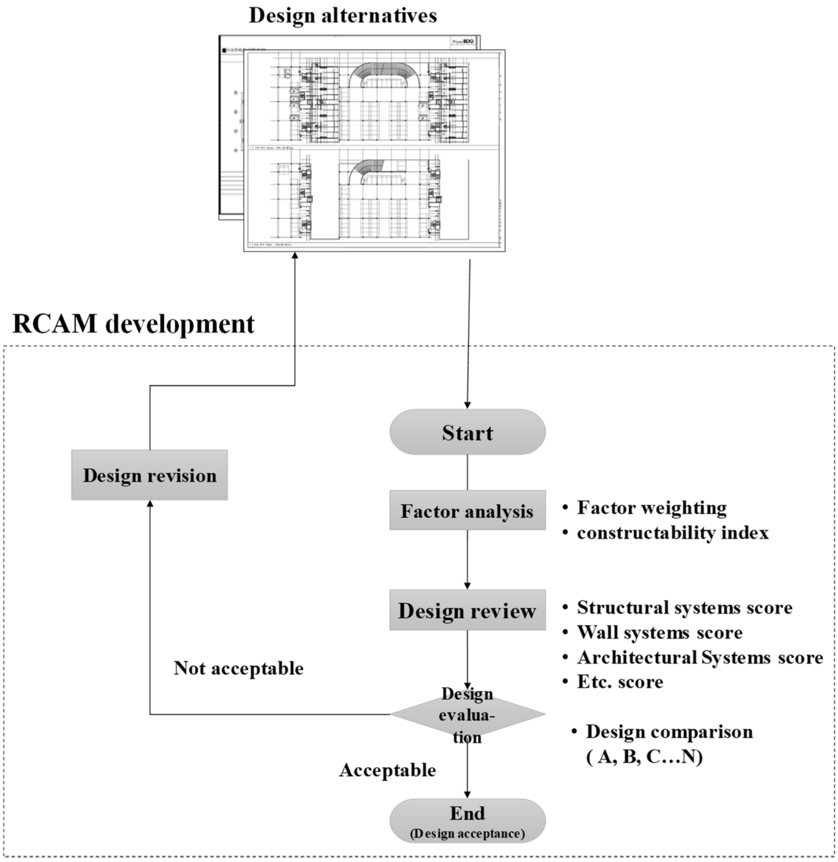

Figure 4: Methodology to develop constructability assessment model of renovation

$$\begin{aligned}\text{Renovation Constructability Score} &\\ = \sum & \textit{Buildable Design Score of Structural System} \\ + \sum & \textit{Buildable Design Score of Wall System} \\ + \sum & \textit{Buildable Design Score of Architectural system} \\ + & \textit{Extra score}(N)\end{aligned}$$

Figure 5: Formula of renovation constructability score

CONCLUSIONS

This research has been conducted to find the constructability factors of building renovation and extension to develop a constructability assessment model for renovation design evaluation. To derive the factors, expert interviews and extant literature were reviewed. For example, in the case of underground space extension construction, factors were derived from the decision flow of the selection of underground space types and risk factors. Including the rest of the renovation works, a total of 27 key factors were derived from the renovation expert interviews and analyses of previous constructability studies. The findings of this research are meaningful because of the preliminary study of the development of a quantitative constructability evaluation model for renovation design alternatives. Prior research on the constructability evaluation of renovation projects is limited to checklists or qualitative evaluation, but it is expected that the evaluation system based on these factors can be established more quantitatively. The extracted factors can be used to develop construction assessment models for renovation projects. In addition, as the problem of ageing buildings is increasing, and effective renovation is being discussed across the world, it can be used in the context of this research industry as well. In future research, AHP or fuzzy methods can be used for deriving the constructability index and quantitative evaluation score. The developed model will help in decision-making when selecting the renovation design. Furthermore, a quantitative evaluation of renovation design is possible if a comprehensive evaluation of constructability, project cost, and time is integrated into one package.

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