A study of the influence factors on modular residential asset

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Abstract

There is a necessity to expand the supply apartment houses for the vulnerable classes. In addition, it is required to manage the assets for public rental housing to improve economic efficiency, such as improving the residential environment to prevent the surge of maintenance expenses due to deterioration. Therefore, it is necessary to supply modular apartment houses that can be constructed with low construction cost in a short period of time. This study aims to derive factors that have the greatest impact on assets in the maintenance phase, and determine the priority of them as part of basic research for efficient asset management of modular construction project. The optimum maintenance cycle and rate are applied as weight factors through a proper formula. As a result, wire rope & pulley, monitoring box, record device, CCTV and information signs are the highest priorities of long-term maintenance contents in economic aspects. In addition, mortar finishing has a high applicability.

Keywords –

Modular; Apartment House; Asset Management; Influence Factor; Maintenance

1 Introduction

1.1 The Background and Purpose of Study

In South Korea, the residence rate of domestic recipients of basic living is 40.2%, but the supply ratio of public rental housing is only 32.9% [1]. Therefore, it is necessary to expand the supply for the vulnerable classes. Also, the increasing number of one and two family members has led to a change in the area of the apartment house. In addition, it is required to manage the assets for public rental housing to improve economic efficiency, such as improving the residential environment to prevent the surge of maintenance expenses due to deterioration [2]. Therefore, it is necessary to supply modular apartment houses which can reduce life cycle cost, particularly in maintenance phase.

The ultimate goal of this study is to create a decision support model for optimal asset management of modular apartment housing. As a first step to achieve the goal, this study aims to derive factors that have the greatest impact on assets in the maintenance phase, and determine the priority of them as part of basic research for efficient asset management of modular construction project comparing to conventional (reinforced concrete) construction project.

1.2 The Scope and Method of Study

The subject of this research was limited to apartment houses constructed by modular construction method. The scope of this research was limited to financial assets except for other type of assets such as human assets and intellectual assets. The scope of period was also limited to maintenance phase. The reason was that the characteristics of modular construction are the most visible in maintenance phase. One of the influential advantage of modular construction is that the module or its components can be easily changed(repaired) and reused.

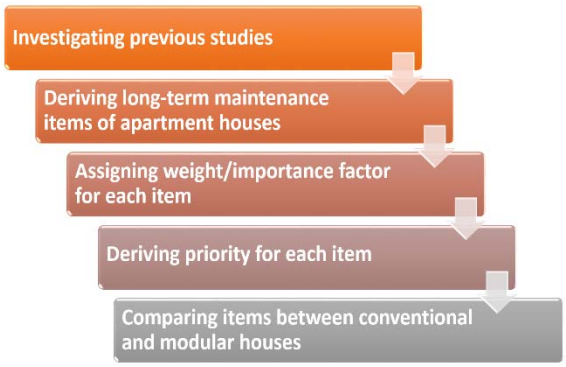

Figure 1. The sequence of this study

This research was conducted in the following sequence, as shown in Figure 1. First, the previous studies of modular apartment houses in asset management aspects involving domestic and overseas literature review were investigated. Second, general long-term maintenance items of apartment houses were derived. Following that, weight factors and importance factors for each item were assigned. Once this was done,

priority for each item was derived. The final step is that long-term maintenance items between conventional and modular houses were compared and analyzed.

2 Literature Review

2.1 Previous Studies

The previous studies related to modular apartment houses in asset management aspects are shown as Table 1.

Table 1 Major research related to modular apartment houses

Author	Title	Main Content
Kim (2011) [3]	Economic Feasibility Study on the Unit Modular Fabrication Method According to the Life Cycle Costing Methodology	Proposing an economic feasibility forecasting model and to apply the model for method of unit modular construction
Kim (2013) [4]	An Economic Analysis of Modular Method for the Urban-type Housing	Conducting an economic analysis by calculating cost and profit by construction method in order to provide basic data for establishing directions for the projects in the future and making decisions
Bang (2014) [5]	An Economic Analysis of Steel Framed Modular Housing: Compared with Case of Urban Type Living Housing of Wall-slab	Analyzing the economics of modular house to vitalize the constructed residential building by modular method and to develop the modular method
Lee (2015) [6]	A Study on Comparative Analysis of Modular Architecture for Movable Accommodation	Proposing demand sensitized movable modular building in order to reduce the financial burden

In fact, one of the advantages of modular construction is reducing construction cost by fast construction. So many studies on the economic analysis of modular apartment houses have been carried out, but the majority of studies have only considered details of construction cost and indirect cost. However, it actually costs more than the conventional method since the infrastructure is not yet built up in South Korea. Therefore, LCC analysis including the details of the modular construction in maintenance phase is needed.

2.2 Introduction to Modular house

2.2.1 General Meaning of Modular house

Modular Construction can be defined as a construction system where volumetric components forming a completed part of a building are produced off-site and transported to the construction site for installation [7].

There are two types of modular construction. One is Permanent Modular Construction(PMC) and the other is Relocatable Buildings(RBs). Permanent Modular Construction “PMC” is an innovative, sustainable construction delivery method utilizing offsite, lean manufacturing techniques to prefabricate single or multi-story whole building solutions in deliverable module sections. PMC buildings are manufactured in a safe and controlled setting, and can be constructed of wood, steel, or concrete. The structures are 60% to 90% completed in a factory-controlled environment, and transported and assembled at the final building site.

A Relocatable Building(RB) is a partially or completely assembled building that complies with applicable codes or state regulations and is constructed in a building manufacturing facility using a modular construction process. Relocatable modular buildings are designed to be reused or repurposed multiple times and transported to different building sites. [8]

2.2.2 Characteristics of Modular Construction

There are four major characteristics of modular construction.

① Fast

The modular construction is based on the dry method, so it is possible to carry out the module production at the factory and the foundation work on the site at the same time [9]. Therefore, the modular construction can be constructed in the rainy season and the winter season, so the construction schedule can be reduced by 50-80% compared to the conventional construction method [10].

② Increasing profit

Compared to the conventional construction method whose labor cost is 50% of the total construction cost, the modular construction costs 20% for the labor cost and 80% for the material and equipment cost. Thus, it is expected that higher profitability as high-function and valuable products [11].

③ Eco-friendly

Since most of the housing materials are produced at factories, the effect of noise and dust reduction is

outstanding by minimizing the site construction when it is constructed close to existing building [1]. From a lifecycle perspective, carbon dioxide and construction waste can be minimized during construction, use and disposal [9].

④ Improving quality

Modular construction is able to move and reuse due to the standardized design of materials and module [10]. It is also possible to maintain the uniform quality of the house as the materials are produced indoors [1].

Among these characteristics, the most effective properties in Korean construction industry is that materials or modules can be easily changed(repaired) and reused. It is because that there is less advantages of cost saving in construction period.

3 Influence Factors

3.1 Long-term Maintenance Items

According to the previous research, the LCC items of apartment house are largely classified into 'Planning Cost', 'Design cost', 'Construction Cost', 'Operation & Minor Maintenance Costs', 'Utility Costs', 'Long-Term Maintenance Costs', and 'Remaining Value & Removal Costs'. When considering the whole lifecycle, the most critical item is long-term maintenance costs.

Table 2 represents the criteria for establishing long-term repair plans according to Enforcement Rule of the Multi-family Housing Management Act in Statutes of the Republic of Korea [12].

Table 2 Criteria for establishing long-term repair plans

Category	Component	Content
Exterior building	Roof	Mortar finishing, Polymer coating waterproofing, Polymer sheet waterproofing, Metal shingle roofing, Asphalt shingle roofing
	Outside	Stitching, Water-based painting
	Outside window	Door (automatic door)
Interior building	Ceiling	Water-based painting, Oil-based painting, Synthetic resin coating
	Inside wall	Water-based painting, Oil-based painting, Synthetic resin coating
	Floor	Underground parking (floor)
	stairs	Non-slip stairs, Oil-based painting
Electricity, digestion, elevator and intelligent home network equipment	Spare power (self-generated) facility	Generator, Switchboard
	Substation	Transformer, Incoming panel, Switchboard
	Automatic fire detection system	Detector, Receiver
	Fire extinguishing system	Fire Pump, Sprinkler head, Digestion water pipe (steel pipe)
	Lift & elevator	Machinery, Wire rope & pulley, Control board, Governor, Door opening / closing device
	Lightning protection equipment & outdoor light	Lightning protection equipment, Security light
	Communicating & broadcasting facilities	Amplifiers & speakers, Broadcast receiving facility
	Boiler & machine room	Power tables
	Security facilities	Monitoring box, Record device, CCTV (closed circuit Television) camera & intrusion detection facility
	Intelligent home network equipment	Home network device, Complex common system equipment
Water supply, gas, drainage and ventilation equipment	Water supply equipment	Feed pump, High water tank (STS, synthetic resin), Supply pipe (steel pipe)
	Gas equipment	Pipe, Valve
	Drainage	Pump, Drain pipe (steel pipe), Waste water pipe (cast iron), Waste water pipe (PVC)
	Ventilation equipment	Extractor fan
(Water) Heating equipment	Heating equipment	Boiler, Water supply tank, Boiler pipe, Heating circulation pump, Heating pipe (steel pipe), Automatic control device, Heat exchanger
	Hot water supply facility	Circulation pump, Hot water tank, Hot water pipe (steel pipe)
Outdoor (welfare) facilities	Outdoor (welfare) facilities	Asphalt pavement, Fences, Children's play facilities, Paving block, Septic tank, Drain & manhole, Entrance, Roof at access road to underground

	parking lot, Bicycle storage, Parking breaker, Landscape facilities, Information signs

Each content has optimum maintenance cycle and rate. These two elements are applied as weight factors in this study on the assumption that the general maintenance period of apartment houses is approximately 50 years [13]. The method of applying weight factors is shown in the formula below.

$$\text{Result value} = \mathrm{Z} \times \frac{y}{100}$$

$$\mathrm{Z} = \frac{50}{x} - 1 \text{ (when } \frac{50}{x} \text{ is an integer value)}$$

$$\mathrm{Z} = \text{natural number of } \frac{50}{x} \text{ using truncate function (when } \frac{50}{x} \text{ is not an integer value)}$$

When x : maintenance cycle (year)
y : maintenance rate (%)
Z : number of repair times

The maintenance cycle (year) is substituted to number of repair times in 50 years, and it is mulipied by the maintenance rate. Some of contents are classified into the method of repair such as partial repair (pr), full repair (fr), full replacement (fm), and full painting (fp). For easy understanding, exterior building category was an example, as shown in Table 3.

Table 3 An example of applied formula

Content	Maintenance cycle (year)	Maintenance rate (%)	Maintenance method	Z	Result value
Mortar finishing	10	100	fr	4	4
Polymer coating waterproofing	15	100	fr	3	3
Polymer sheet waterproofing	20	100	fr	2	2
Metal shingle roofing	5	10	pr	9	0.9
	20	100	fm	2	2
Asphalt shingle roofing	5	10	pr	9	0.9
	20	100	fm	2	2
Stitching	25	5	pr	1	0.05
Water-based painting	5	100	fp	9	9
Door (automatic door)	15	100	fm	3	3

3.2 Priorities of Long-term Maintenance

If all contents are analysed in the same way as above, they can be prioritized as shown in Table 4. It represents top 20 items among all the long-term maintenance contents.

Table 4 long-term maintenance contents ranked top 20

Rank	Content	Result value	Maintenance method	Applicability in modular
1	Wire rope & pulley	9	fm	N
1	Monitoring box	9	fm	N
1	Record device	9	fm	N
1	CCTV (closed circuit Television) camera & intrusion detection facility	9	fm	N
1	Information signs	9	fm	N
6	External water-based painting	9	fp	N
6	Ceiling water-based painting	9	fp	N
6	Ceiling oil-based painting	9	fp	N
6	Ceiling synthetic resin coating	9	fp	N
6	Inside water-based painting	9	fp	N
6	Inside oil-based painting	9	fp	N
6	Inside synthetic resin coating	9	fp	N
6	Stairs oil-based painting	9	fp	N
14	Boiler pipe	5	fp	N
15	Underground parking (floor)	4.5	pr	N
16	Home network device	4	fm	N
16	Feed pump	4	fm	N
16	Extractor fan	4	fm	N
16	Drainage pump	4	fm	N
16	Mortar finishing	4	fr	H

If the result values are same, the maintenance method would become the standard of rank. The order is full replacement(fm) > full repair(fr) > full painting(fp) > partial repair(pr). Additionally, the applicability in modular houses was considered whether highly(H) or normally(N) applicable. Only ‘mortar finishing’ has a high applicability in modular construction. The reason is that it can be fully repaired or replaced as a module. It was difficult to find clear difference of long-term maintenance items between conventional and modular construction. However, table 4 is a result of fundamental research to derive influence factors on modular residential asset and represents top 20 long-term

maintenance contents. As the research continues, the ranking items will support to decide the prior scope of economic analysis on modular maintenance asset. Since there are too many considering economic maintenance items, the prior influence factors are needed.

4 Conclusions

In this study, research was carried out to derive influence factors which are long-term maintenance items of apartment houses. Also, the priority of items was derived through assigning weight factors. However, most of prior items have little difference between conventional and modular construction.

On the whole, more considerations and weight factors are needed. The maintenance method should be weighted as a number and included in applied formula according to objective criteria. Also, construction materials or works should be repaired as a whole unit such as wall and floor itself, not separately. For instance, roof can be replaced as a module in modular construction if mortar finishing, polymer coating waterproofing and metal shingle roofing are needed to repair simultaneously. Even though a module is installed as one room at construction site, it is possible to replace each part in maintenance phase. This is because modules are made up of bundles of individual components such as exterior/inner wall, ceiling and window.

In addition, this study was focused on repair of long-term maintenance items. In order to highlight 'reuse' which is strong advantage of modular construction, considered period or phases should be increased. If the remaining value and removal phase are considered, there must be lots of items which have high applicability and strength to modular construction.

It was so hard to analyze influence factors on modular residential asset with scarce economic information. This study was the first step to manage modular residential asset. In conclusion, it was meaningful study as a leading research. Therefore, the results of this study will lead to a study on asset management of modular houses in the future.

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References

[1] Joo K., Lee E., Cho J. and Yoo W. A Study on the Development of Housing Management Model in a Small Scale Apartment Complex. *The report of Land & Housing Institute*, Korea Land & Housing Corporation, 2016

[2] Wang W. and Lim S. A Study on the Planning Characteristics of the Infill System with Consideration of the Variability of Longlife Housing. *International Conference on the Architectural, Civil and Hydraulics Engineering(ICACHE),* 2015.

[3] Kim K. and Lee Y. Economic Feasibility Study on the Unit Modular Fabrication Method According to the Life Cycle Costing Methodology. *Journal of the Architectural Institute of Korea*, 27(12):207-214, 2011.

[4] Kim T., Jeong J. and Lee H. An Economic Analysis of Modular Method for the Urban-type Housing. *Proceedings of the Conf. on Korea Institute of Building Construction,* 2013(1):399-402, 2013.

[5] Bang J., Jeon J., Park J., Kim J., Kim G. and Cheon Y. An Economic Analysis of Steel Framed Modular Housing: Compared with Case of Urban Type Living Housing of Wall-slab. *Land & Housing Institute(LHI) Journal,* 5(4):305-314, 2014.

[6] Lee J., Son J., Jeong W. and Lee J. An Economic Feasibility Analysis on the Movable Modular Lodging Buildings. *Korean Journal of Construction Engineering and Management,* 16(5):12-20, 2015

[7] Harvey M., John E. and Donna L. Prefabrication and Modularization: Increasing Productivity in the Construction Industry. *National Institute of Standards and Technology*, 2011.

[8] Modular Building Institute, *http://modular.org/*

[9] Lee D. and Kim K. A fundamental study for applying of Unit modular housing production system in the domestic. *Korean Journal of Construction Engineering and Management,* 14(5):3-11, 2013

[10] Hwang J., Choi S., Lee J. and Kim Y. Development of Bill of Service Framework for Modular Housing Construction. *Korean Journal of Construction Engineering and Management,* 15(5):138-146, 2014

[11] Lim S., Park K., Chae C. and Kwon B. A Study on Factory Product System of Unit Modular Housing System in Korea, United States, Japan, Europe. *Journal of the Korean Housing Association,* 18(4):27-35, 2007.

[12] Statutes of the Republic of Korea. Criteria for establishing long-term repair plans. *Enforcement Rule of the Multi-family Housing Management Act*, 7(1).

[13] Statutes of the Republic of Korea. Year of apartment house. *Enforcement Rule of the Corporate Tax Act*, 15(3).