Sustainable Design and Construction of a Prefab Housing System with High Performance

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ABSTRACT

This paper aims to conduct an empirical test-bed research to improve design and construction process of the prefab multi-unit housing accommodating 50 college students, based on integrated co-works with different stake-holders (clients, architects, builders) and involving non-profit organization such as Habitat for Humanity Seoul. The purpose of the study is not only to develope optimal design technologies for the higher thermal efficiency but also to identify the ways in which the prefab houses could be supplied for low income groups.

INTRODUCTION

In Seoul, the capital of the Republic of Korea, the urban area developed to be quite overcrowded due to rapid economic growth and urbanization. After 2000, the population of Seoul had a steady while the number of households increased. This is because of the shift in the nuclear family composition, in which single or two-person households became more typical. With this, a housing shortage occurred in the urban area due to the increase in the number of households. The major concern in this housing shortage due to urbanization is the autonomy of the socially disadvantaged. As they are weak in terms of social standing, their residential environment is very poor. Therefore, in all levels of society the interest in the disadvantaged has increased, and diverse housing welfare projects for the socially disadvantaged as a low income group are actively being implemented. With this, the improvement of the residential environment is also becoming a critical issue.

In Korea, modular construction, which was presented for the first time in 2003, is proposed as one of the solutions to resolve this problem. The prefabricated house was presented as an alternative to resolve the problem of housing distribution for low income residents and socially disadvantaged persons in the urban area, and the current modular construction method that was introduced to Korea over 10 years ago is rapidly growing and is also recognized as a new construction system.[6]

Modular housing has become a very interesting issue, not only in Korea but also in other countries. In Korea, the modular construction system is generally applied for a range of purposes such as residences, commercial buildings, schools, hospitals, increasing during its short 10-year history, but there are still many problems to resolve.[7] This research focuses on potential applicability of the prefabricated house and the high-quality house distribution based on an empirical study on the modular house as a future method of residential construction with great potential.

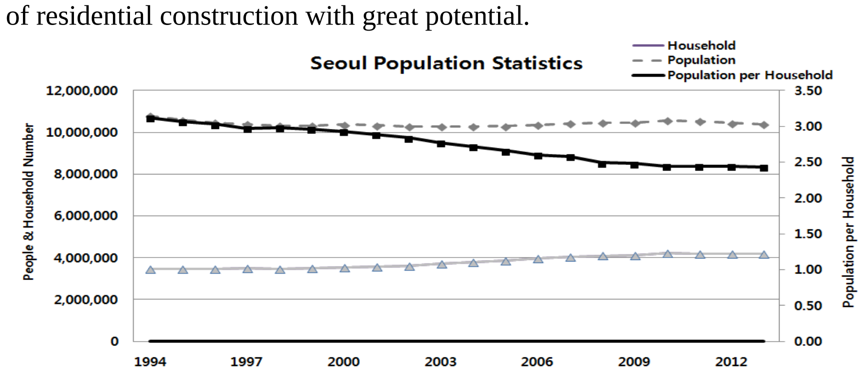

Figure 1. Seoul Population Statistics (National Statistical Office of Korea)

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Background to Domestic Prefab System Housing

Most of the domestic modular houses from 2003 to 2008 were applied for education and military facilities, as the special characteristics of the modular construction were suitable to these applications. In modular construction the construction period is reduced, demolition and reuse after the life/duration of the building is easy and the application of new methods according to new policies is easier, as they are public facilities. In Korea since 2000, modular construction has been applied in different sectors such as for export, residence, the 2nd Antarctic Base, etc., and particularly in the residential sector, the Ministry of Land, Infrastructure and Transport revised the 'Industrialized Residence Acknowledgment Standard' for the first time in 2006 to enable the application of modular construction[7].

The residential sector in modular construction covers all areas, such as detached house, dormitory, small rental house, and mid-to-high-rise residences. This research will look at a 50-person capacity university dormitory, built recently with the modular construction method that has been gaining attention. Based on the above case, this research proposes the possibility of a model of house distribution for low-income groups through the cooperation of the government and private sector, by implementing an empirical study on a residence for students migrating from other provinces.

Characteristics and Need for A Prefab System Housing supply

The modular construction system is comprised of the factory manufacture/process of frameworks, electric works, construction equipment works and finishing and the assembly and installation of prefabricated parts on-site, the strongest point of which is the reduction of the construction period, procurement of equal/standardized construction quality, easy demolition process for aged buildings and the reusability of subsidiary materials. It can properly respond to working environment avoidance and to the demand for a reduced construction period. Also, through materials and specifications standardization in the factory the quality is uniform based on automated production technology.

The factory-manufactured prefabricated house is classified into different types according to the distribution and construction method, but the definition in this research is as follows:[8]

- **Modular House** : House composed of prefabricated parts that is constructed according to the local government or regulation of the construction site. House installed with module units transported from the factory to site.

When the material process and construction are fully performed on-site, problems can emerge such as deterioration of construction quality, increase in the construction price and extension of construction period, etc. In current domestic modular construction, the modules are generally manufactured for site construction, and therefore improvements in production efficiency are required.[2] Thus, even when the modules are assembled in the factory, the necessary materials must be detailed and standardized for every order/phase from the module manufacture and installation for an easier construction process. This will shorten the site construction period and improve the quality. The reduction of the construction period and improvement in quality results in a cost reduction, and this is the strongest point of the prefabricated house. Figure 3. shows a comparison of construction price composition between the British site construction method and the small and large modular method (OSM: Off-Site Manufacturing). The materials cost in the general modular method is larger than in the existing site construction method, in which the wall and floor of the modular house is basically formed by 2 floors.

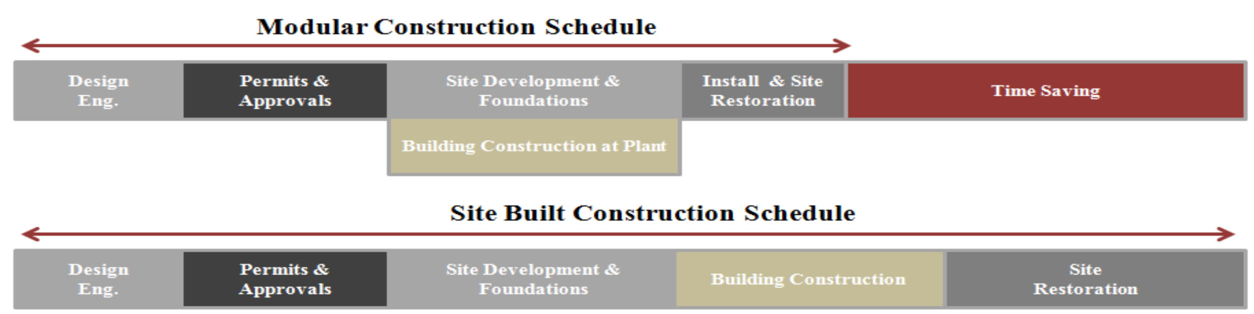


Figure 2. Advantages of a Modular Construction Schedule

Therefore, when the modular method is applied it must be considered that the material quantity is higher than in the existing site method. However, the reduction in unit price for quantity purchase, and reduction of loss on site can be considered as another strength of the modular method

Also, in the case of this factory-manufactured prefabricated houses, the building using of identical and standardized Materials simplifies the dismentlement at the end of the life, therefore the reuse value is also excellent due to the subordinate materials. This excellent reusability is a critical factor of the eco-construction method that may overcome the faults of waste production in the existing construction method.

In Korea the modular construction system includes reinforced concrete floor plate, and wet process as fire-proof paint in the ground plate phase considering the domestic residential environment. As shown in Figure 4, the modular construction system of this research requires production improvement and wet processes; sufficient design considerations, construction process and manufacturing planning to prevent cost increase for buildings over 5 floors, for which 2 or more hours of fire-proof treatment is required.[1]

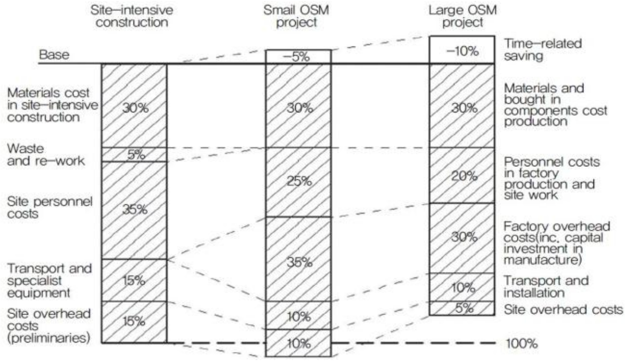


Figure 3. Comparison of Modular Construction Cost

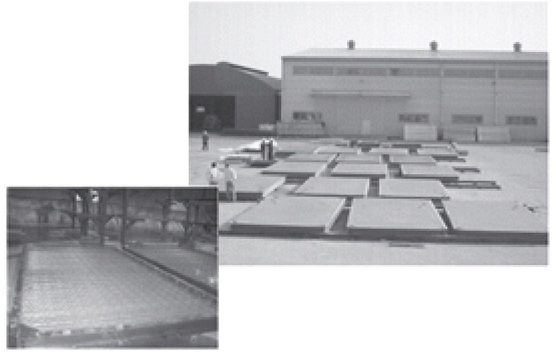


Figure 4. Deck Plate & Wet Construction Methods Case

CASE STUDY

"The Dreaming Attic for Student Residence CY"

As stated in Figure 5, Seoul is currently the city with the highest population density among all cities in OECD countries, at 16,700 person/㎢. This is 3 times denser than London. Many students come to the city to study in different universities but considering this high population density, it is actually difficult to satisfy the demand for student housing, placing a burden on the students. For this reason a project was implemented in which prefabricated houses were constructed on top of public parking lots managed by local governments to increase the added value of public spaces, and these were distributed to the socially disadvantaged in the form of rental houses. This became an object of empirical study as an alternative to using the ground space of the public parking lot, an indispensable facility in every urban area. Actually, the Dreaming Attic for Student Residence CY, which was completed in February 2014, is a representative case in which the NGO, Habitat for Humanity Seoul and Seodaemun district office cooperated to expand a building of 1F and 1 basement where there is a public parking lot for residents of the area into a 1 basement and 4-floor apartment building with housing units from the second floor to the fourth.

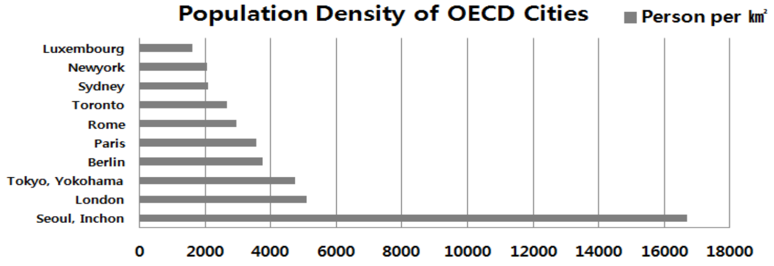


Figure 5. Population Density of OECD Cities (per/㎢)

Residents were strictly selected from nearby university students, and provided with a pleasant residential environment at a low cost. Figure 6 shows the assembly phase of the actual construction process. The project was implemented through cooperation between the NGO, the local government, the constructor and the module manufacturer to resolve the parking problem and to distribute low-cost, pleasant residences.

PERFORMANCE ANALYSIS & DEVELOPMENT

Environmental Performance of Prefab System Housing

Korea's Construction Act regulates the heat transmission coefficient in the basic insulation sector. Also, apartment buildings with 500 units or more are assessed in terms of preventing condensation to secure an adequate interior thermo-residential environment. In the anti-sweating performance assessment the value must be lower than the standard as the TDR (Temperature Difference Ratio) as stated in Equation 1. <Table 2> calculated the indoor minimum surface temperature of the wall using the computer simulation program PYSIBEL Trisco Ver.12 to interpret the electric heat of the wall. It was found that the weakest/poorest right angle TDR satisfied the domestic standard by scoring 0.233, showing performance equal to that of general apartment buildings built with reinforced concrete. The high-performance insulation effect of the prefabricated house secured a good indoor thermal environment, a reduced construction period and economic advantages. Given that the domestic climate has a clear difference in terms of the four seasons, a higher insulation performance is required when compared to prefabricated houses used in other countries. Table 3 shows the legal limits of the domestic apartment anti-sweating design standard. The target building of this research satisfies the existing apartment building standards and demonstrated an insulation performance similar to that of general residential buildings. While higher insulation performance can be secured, this will increase the basic unit price of the construction, and therefore we only showed the most optimal insulation performance.

Table 1. Introduction of Case Study ("Dreaming Attic for Students of CY")

Classification	Contents	View
Building Name	Dreaming Attic of CY	
Address	98-13, Cheonyeon-dong, Seodaemun-gu, Seoul, Korea	
Total Floor Area	785.53 ㎡	
Building Scale	B1F, 4F (B1F, 1F - Parking Area)	

Figure 6. Modular Field Construction Case

$$TDR = \frac{T_i - T_m}{T_i - T_o} \quad \text{- Equation 1}$$

TDR : Temperature Difference Ratio

Tm : Indoor Minimum Surface Temperature (℃)

Ti : Indoor Air Temperature (℃)

To : Indoor Air Temperature (℃)

Table 2. Insulation Performance of Wall Junction (Prefab System Housing)

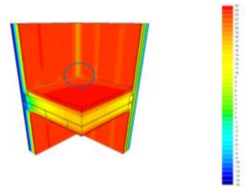
Plan	Simulation Result (PYSIBEL Trisco)		
		Heat Transmission Coefficient :	K : 0.27 W/㎡•K
		TDR Standard	0.250
		TDR (Ti:25, To:-15)	0.233
		TDR (Ti:20 To:-15)	0.232

Table 3. Standard of Assessments to Prevent Condensation of Apartment Housing

Region			TDR Value		
			Ⅰ Area (North)	Ⅱ Area (Middle)	Ⅲ Area (South)
Gate	Exterior Door Fire Door	Door	0.30	0.33	0.38
		Door Frame	0.22	0.24	0.27
Wall Junction			0.23	0.25	0.28
Exterior Window		Center of Glass	0.16 (0.16)	0.18 (0.18)	0.20 (0.24)
		Corner of Glass	0.22 (0.26)	0.24 (0.29)	0.27 (0.32)
		Window Frame	0.25 (0.30)	0.28 (0.33)	0.32 (0.38)

A New Housing Supply Model for Low-income Groups

In existing construction projects there were economic problems and difficulties in site selection. These difficulties resulted in an increased construction price, and there was a perception that the prefabricated houses were expensive; therefore, it was necessary to change that perception. The new project model, "Dreaming Attic for Student Residence CY," is indispensable for presenting the necessity of prefabricated housing and guaranteeing the welfare cooperation for all of society. But it is a fact that the investment required of the government and enterprises is still a problem to resolve. In addition, the problem of management after construction is significant. It is important to provide more benefits to the socially disadvantaged, and to distribute these equally through transparent management and administration.

As we can see in Figure 7, through this project model the government, NGO, constructor, module manufacturer, the people and the disadvantaged will all gain great benefits. The government will have the benefit of a direct solution to a social problem, the enterprise will gain the advantage of experience through manufacturing and constructing prefabricated houses, changing perceptions of prefabricated houses and making a disadvantaged will all gain great benefits. The government will have the benefit of a direct solution to a social problem, the enterprise will gain the advantage of experience through manufacturing and constructing prefabricated houses, changing perceptions of prefabricated houses and making a social contribution. Above all, through the cooperation and social contribution of the government, NGO, constructor and manufacturer, more socially disadvantaged persons will receive more benefits, producing positive effects in general.

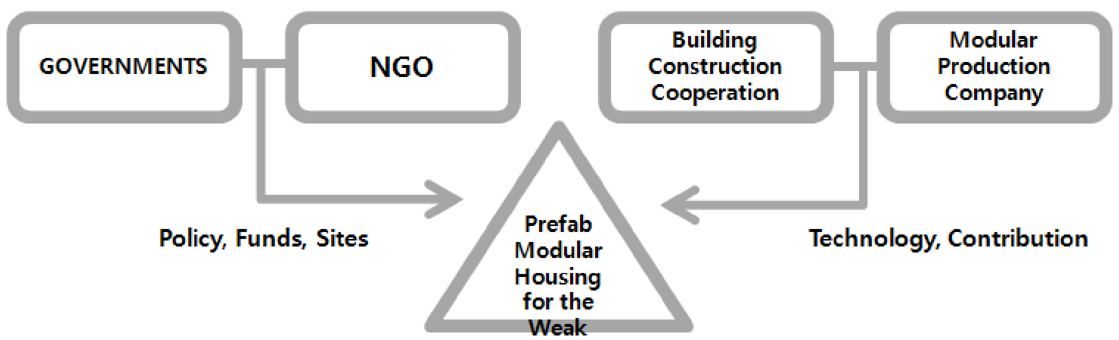


Figure 7. Concept of a Housing Supply Model

CONCLUSION

In this research we presented a project model based on the above-described empirical cases for a wider application and diffusion of prefabricated houses. The application of prefabricated system housing can be an excellent alternative that satisfies the demands resulting from high population density, the increase of single-person households, and the need for inexpensive small-unit housing and demands for better residential environment, etc. Nowadays, a better residential environment with uniform performance and quality can be provided through optimal performance evaluation within a scope where excessive design is avoided by reducing the construction period through the use of prefabricated houses.

In the prefabricated housing system, construction, equipment and electric works excluding civil and landscape works are performed in factory by the manufacturer, therefore the role allocation between the contractor and subcontractor is very different from that of existing site construction methods. Thus, with the development of the new module technology, the module manufacturer performs the new project model incorporated with the constructor and so the benefit is provided to everyone and is made available to society through its application in a housing welfare project. It will no longer be a simple economic activity, but an indispensable housing welfare project model for low income and disadvantaged persons and an excellent response to the government policies.

In addition to the public parking lot, it is necessary to expand the project by procuring diverse project sites to provide more benefits for the disadvantaged. This project model is applicable not only in Korea but in all other countries, and considering that it strengthens the benefits of prefabricated housing it will be an ideal alternative for us to open the future. The modular construction system which guarantees economic advantages based on a high technological level and experience offers a new paradigm in housing welfare projects through the improvement of the residential environment for low-income and disadvantaged persons living in inefficient residential spaces, through the cooperation and assistance of the government and diverse NGOs, and the probability of its application was clearly certified. More interest needs to be taken in housing provision methods for low-income and disadvanted persons.

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