The 6th International Conference on Construction Engineering and Project Management (ICCEPM 2015)
Oct. 11 (Sun) ~ 14 (Wed) 2015 • Paradise Hotel Busan • Busan, Korea
www.iccepm2015.org

A Study on the Supply Process of Unit Modular Housing through a Comparison of Cases

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Abstract: The purpose of this study is to conduct a comparative analysis between Korea and the United States of the supply process of unit modular housing at both the factory production phase and the transportation and lifting phase, as part of an attempt to invigorate the unit modular housing market in Korea. Unlike the practice in the United States, one of Korea's unique characteristics is that the floor is constructed with reinforced concrete and hot water heating system. To do this, the wet method in Korea is used that includes concrete placement, curing and constructing hot water floor heating system at the factory production phase, which results in a longer production time and also requires the lifting of heavier loads. In the United States, interior and exterior finishing works of modular housing are performed by different companies, and the distance between the unit module factory and the construction site is quite far. This kind of dualized production structure may cause confusion when it comes to schedule management, procurement management, and stock management. Moreover, problems caused by external environmental factors such as wind and rainfall were reported in the course of long-distance transportation. The results of this case comparison are expected to provide fundamental data that will reduce the amount of trial and error in the unit module production, transportation and lifting work in Korea, which has a comparatively small number of unit modular housing cases.

Keywords: modular housing, unit module, case study, supply process

I. Introduction

In recent years, the limitations of the existing construction system including stagnant productivity, excessive CO^2 emissions, and excessive construction wastage have come the fore, and the unit modular housing method has been catching the industry's attention. In the unit modular technique, a cubic-type steel structure frame is produced at a factory, and then walls, windows and doors, and diverse interior and exterior materials, facilities, and electric wiring are equipped within it in the factory. Next, the unit module produced is delivered to a construction site, and then assembled [1]. Therefore, when the unit modular housing technique is partly prefabricated at a factory and then installed at the site, builders can achieve a reduction in the construction duration, as well as improvements in productivity and quality through factory prefabrication and dry work.

However, the history of unit modular housing in Korea is much shorter compared with other advanced countries, and for this reason Korea has a limitation in that the technical maturity in the field falls behind. In addition, Korea lacks the systematic mass production or assembly line systems to produce unit modular housing found in the U.S., Europe or Japan, as the unit modular housing market is still small in Korea, and the related manufacturers are small, as well. In addition, the works are frequently done manually at a factory, which implies that the factory production is not being used effectively. In addition, as the basic frames are manufactured at a factory, while the rest of the works are done at the site, it is not significantly differentiated from the conventional construction method. Taking these aspects into consideration, the advantages of the unit modular housing such as improvements in productivity, reduction in carbon dioxide emissions or decrease in construction waste have not yet been utilized to the fullest extent. For these reasons, there is an urgent need to research and develop a construction management technique that resolves the aforementioned problems and overcomes the limitations. As such, if the differences between the advanced countries and Korea in terms of the work procedure and process can be understood through a comparative analysis, it will be of great help in bringing about an improvement in construction management in Korea [2].

The purpose of this study is to conduct a comparative analysis of the supply process at the factory production phase and the transportation and lifting phase of unit modular housing between Korea and the United States, as part of an attempt to invigorate the unit modular housing market in Korea. To do this, unit modular housing cases in the U.S. and Korea were selected and then the construction process for unit modular housing was defined by case. Then, the differences in the cases between the U.S. and Korea are compared and analyzed.

II. Advantages of the Unit Modular Housing Method

The unit modular housing construction method has been

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creating a new paradigm representatively consisting of factory production, transportation and assembly, which is greatly different from the conventional field-centered paradigm. First, economies of scale in mass production can be expected from the factory prefabrication of unit modules. Second, quality control and safety management can be improved because the unit modules are produced within a factory. Third, the unit modular housing construction method can bring about a remarkable decrease in the construction duration compared with the field-centered construction process due to their prefabrication at a factory. Fourth, it is possible to reduce the construction cost and complaints related with the construction by reducing the construction duration. Fifth, the prefabrication of unit modules at a factory is not affected by weather or season [2].

III. FACTORY PRODUCTION, AND TRANSPORTATION AND LIFTING

A. Selection of the cases

1) In the U.S.

The B Project was in the second phase of Atlantic Yard Regeneration Project carried out in Brookline, NY by Company S to build a 32-story (98m) residential tower for public rents or sell. The gross area of the B Project was 32,144 m², designed to hold about 363 apartments and commercial facilities(371m^2), and 146 car parking spaces. Taking into account that it is the highest unit modular structure in the world under construction. However, there were significant commercial and design issues in this project, hence the owner decided to switch from modular methods to stick-built. The building may take four years, not two, and $146 million impairment potential loss [3]. Although these issues can be caused controversy, the cutting-edge technologies and construction process of existing modular housing project can be identified from it, the B Project was selected as one of the cases to study.

2) In Korea

As mentioned previously, the unit modular housing market in Korea has not yet been invigorated. For this reason, it was very difficult to select one building as a case for the comparative study. Considering this fact, the mock-up building built by Company K was selected as the case, but the results of an analysis of diverse projects carried out by companies leading the unit modular market in Korea were also included.

B. Major process of the unit modular housing construction

The major process of the unit modular housing construction is depicted in Figure 1. The foundation work at the site of the entire process has no significant difference from the conventional construction. Also, the assembly process of unit modules is very similar to the assembly of steel components into a frame, and the conventional construction method is applied in the facilities work and the finishing work. Therefore, in this study the processes from factory production to the lifting of the module will be compared.

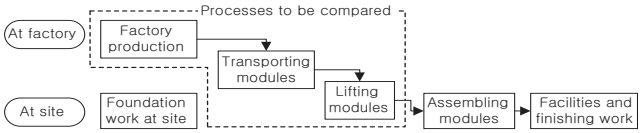


Fig. I Major process of the unit modular housing construction

C. Factory production phase

1) In the U.S.

The steel frames used in the module are manufactured at Company B Steel located in Lynchburg, Virginia and transported to Navy Yard, New York using a train or a truck. The 'Bathroom Pod' is assembled into the module frame with an infill. Next, the mechanical works are performed, which means that all the facilities including machines, electricity, piping and extinguishers are installed into the module. Last, the internal partition work, the interior work, the painting work, and the exterior work are completed (See Table 1).

2) In Korea

Most of the housing in Korea uses concrete slab and a floor heating system using hot water. For this reason, this is also featured in the unit modular housing. Concrete slab is placed in Korea after the steel frame is built. Next, the exterior work, facilities and electricity work, and the interior work are carried out successively (See Table 1).

D. Transportation and lifting phase

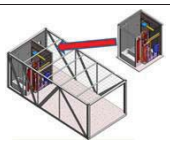
1) In the U.S.

In the B Project, the modules prefabricated at Navy Yard were transported to and assembled at Atlantic Yard. For more efficient transportation of the unit modules, Company S and Company F used walkie-talkies for smooth communication. A communicable system was also installed both in the trailer and in the DOT Escort vehicle, which allowed the drivers of the two vehicles to communicate with each other. A tower crane was used to lift the unit modules at Atlantic Yard (See Table 1).

2) In Korea

The mock-up building constructed by Company K selected as a case in Korea was built as a factory within its subsidiary company as mentioned earlier, so that no packaging and open-storage were needed, and the

TABLE I
ANALYSIS OF THE MODULAR CONSTRUCTION PROCESS

	phase	Factory production phase				
U.S.	phase	manufactured modular steel frame	integration of subassemblies	MEP installation in factory	modular interior & exterior finishes	Module package
	concept					
	Activity	-Layout module -Installation of flame retardant ceiling -Installation of column warp -Installation of external and end collar beam wrap -Installation of fire retardant separation walls -Drilling for core MEP	-POD installation -Installation of MEP hangers and cartridge in the hallway -Installation of internal separation -Installation of MEP hangers and cartridge on the soffit -Planning of the HVAC duct -Planning of the sprinkler system -General plumbing plan -Electrical construction plan -Completion of mini-connection points of all MEP -Soffit installation	-Dry wall finish and painting finish/ loading and unloading trim materials -Installation of external wall panels	-Installation of a kitchen -Shelf finishing -Installation of MEP trims -Installation of door frames -Installation of floor material	-Protection cover
Korea	phase	Frame work	Floor work	Exterior work	Facilities, Electric & Interior work	Module package
	concept					Nothing particular
	Activity	-Carrying-in of materials -Member processing and frame production -Assembling unit frames	-Reinforcement placing -Welding joints -Con'c placement and curing	-Installation of exterior materials	-Facility planning -Electrical wiring -Installation of floor finishing material -Installation of internal walls -Installation of the ceiling	Nothing particular
	phase	Transportation and lifting phase				
U.S.	phase	Open storage(If necessary)	Loading	Transport	Carrying-in	Lifting
	concept					
	Activity	-Transport of modules to the open storage field -Module protection	-Trailer check -Module loading -Module fixation and packaging check	-Transport of modules	-Missing parts check -Confirmation of the unloading place at the site -Unloading modules	-Selection of the crain position -Lifting of the modules
Korea	phase	Open storage(If necessary)	Loading	Transport	Carrying-in	Lifting
	concept	Nothing particular				
	Activity	-Transport of modules to the open storage field -Module protection	-Trailer check -Module loading -Module fixation and packaging check	-Transport of modules	-Missing parts check -Confirmation of the unloading place at the site -Unloading modules	-Selection of the crain position -Lifting of the modules

distance. However, this is an exceptional case. The unit modules are usually transported at least at a certain distance in Korea. A truck crane is generally used to lift them at a construction site (See Table 1).

IV. COMPARATIVE ANALYSIS

Unlike the cases in the United States, one of the unique characteristics in Korean home construction is that the floor is constructed with reinforced concrete and hot water heating system. To do this, the wet method in Korea is used that includes concrete placement, curing and constructing hot water floor heating system at the factory production phase, which results in a longer production time and also requires the lifting of heavier loads. Depending on the unit modular construction situation, the concrete slab can generally be worked on only after the steel beams are formed on the lower part, as shown in Figure 2.

(a)Concrete placement (b) Curing

Fig. II Floor construction of the unit modular construction (in Korea)

In one of the United States cases considered, interior and exterior finishing works of the modular housing were performed by different companies, and the distance between the unit module factory and the construction site is quite far. This kind of dualized production structure may cause confusion when it comes to schedule management, procurement management, and stock management. Moreover, problems caused by external environmental factors such as wind and rainfall were reported in the course of long-distance transportation.

Another feature of the U.S. case is a high-rise building with 32 stories high. In order to lift unit modules to higher floor levels, a crane is needed. For this reason, a tower crane is used in the B Project. On the other hand, low-story unit modular housing is chiefly constructed in Korea, and the lifting height is not a key consideration factor.

V. CONCLUSION

The history of unit modular housing construction in Korea is extremely short compared with advanced countries, and its technical maturity is not yet sufficient. However, considering the advantages of the unit modular housing construction method, including improved productivity and quality, it will inevitably be applied to diverse types of building structures, and to high-rise buildings as well. Therefore, in this study two cases were selected; one from the U.S. and the other from Korea. The supply process of the unit modules from factory production to transportation and to lifting was investigated in each case in order to conduct a comparative analysis of the cases in the U.S. and Korea.

Since there was used that the wet construction method of concrete slab includes hot water floor heating system in Korea, it was found that it took a relatively longer time to place concrete and lift the unit modules. The concrete load had a great influence on much of the process including the need for a larger crane. As the steel frame and the interior and the exterior works are performed by different companies, transportation became very important in the process management. Lifting height was one of the most important variables to be considered, as it was built as a high-rise building.

It is expected that the findings of this case comparison will provide fundamental data that enables builders in Korea to reduce the amount of trial and error in unit module production, transportation and lifting work. However, this study has a limitation in that only two representative cases were selected, the one of the cases, the B Project has encountered diverse issues in its actual construction and the working process of the cases was not explicitly analyzed. In future research, more cases should be analyzed, and furthermore, a comparative analysis of more concrete and descriptive factors should be carried out, including on the working method and procedure.

ACKNOWLEDGEMENT

This paper was supported by the Korean Institute of Civil Engineering and Building Technology (KICT) under the Strategic Research Project (Construction Technology Development for One-day Housing).

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