Localization Transformation of Industrial Residential System: A Case Study on SI System in China

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Abstract. The SI (Skeleton-Infill) System originated from Japan and introduced to China in 2006. The build-up projects proved the technical feasibility of SI System in China. However, the localization transformation of SI System has not completed in China. Based on literature review, the main determinants of influence mechanism are revealed to be housing ownership model, residential scale, and residential form. The content analysis revealed the potential influences on the uptake of SI System in China. This research sought to reveal the influence mechanism of social environment on industrialized design system. The practical value of the research is providing guidance for policy makers and designers to help them improve design quality of SI System in China.

1. Introduction
Prefabricated construction originated from Europe, then spread overall the world. Countries which started late in prefabricated construction usually start by learning the technology from other mature countries. Since different countries have different social environment, it is necessary to localize the transform and the design method from other countries. Singapore is a successful case of Learning - Transformation mode. Although a large amount of research has been dedicated to the difference of construction technical system from different countries, little is known about what factors have affected the localization transformation of industrial residential system.

China and Japan are very similar in climate zones and population density. Therefore, since 2000, Japan has become the main reference system for the development of China's prefabricated housing. China introduced the Japanese Skeleton-Infill System (SI System) and the assembled monolithic concrete technology. In 2016, Chinese government issued relevant documents and proposed that proportion of prefabricated building in the new buildings would be improved to 30% for the next 10 years. There is no doubt China’s prefabricated housing will enter a rapid development period. Besides, SI System is a high-quality, sustainable and long-life industrial residential system, the transformation mechanism of SI system is expected to enlighten the future development of Chinese industrial residential system.

2. Literature Review
Although on-site construction is very popular across the global construction sector, off-site construction has started to reveal its significance in sustainability, safety, efficiency and so on (Jaillon,
2009). Japan produces over 70,000 manufactured homes a year, which has become one of the most active practitioners of manufactured construction in the world; over 30% of new houses built are prefabricated housing in UK (Jiang et al., 2018).

The development of off-site construction of each country or region is different. Steinhardt and Manley have compared housing industry data in the six countries presented four key determinants of prefabrication uptake: annual dwelling completions, new housing versus renovations, housing ownership models, and housing types. However, the data currently available is insufficient to facilitate more definitive analysis (Steinhardt and Manley, 2016). Also, there is a study about different patterns of regional modularity between different countries, then the researcher has found out the United States as the most oriented to modularity and Japan as the country most oriented to integration (Yu et al., 2015).

The SI System origin from Stiching Architecten Research (SAR) theory proposed by John Habraken in 1960s, and influenced by the idea of Open Building. The SI System is formed at 1990s in Japan, which developed into Long-life Quality Housing Plan in recent years. Apparently the development SI System never ends because shortage of construction workers and the changing lifestyle of residents in Japan (Minami, 2016). While the SI System not only developed in Japan, Korean certification system for long-life housing established in 2014, Kim and Hwang utilized preliminary data for improving the system through the analysis of evaluation items in the certification system (Kim and Hwang, 2017).

3. Research methodology

3.1 Selected determinants
This paper focuses on those determinants which have direct influence on design process of SI system, particularly amalgamated dwelling, because the vast majority of Chinese residential building is amalgamated dwelling. Restrictions on building types drastically limit the range of potential determinants that can be examined. There are other important determinants which are not covered as they fall out-side this clearly defined scope, such as supplier, retailers, and manufacturers (Jiang et al., 2016). Regardless, all stages in the industrial residential system have provided important pre-conditions for transformation, and these are yet to be comprehensively investigated in the literature.

This selection of determinants follows Pries and Janszen, 1995. They have drawn particular attention to the dual role of government and consumers by encouraging building new works. China and Japan have respective regulations for housing designs, which has led to different residential forms and residential scales for two countries. The consumers, who are living in the building also have great influence on residential forms and residential scales, since the living culture is quite different between two countries. Boadu’s(2014) article of public housing has put forward the idea about the new housing funding models which can have significant bearing on the likelihood by introducing new construction methods. The previous reports have provided general variable of the important determinants for localization transformation of the industrial residential system.

3.2 Methodology
The research is divided into three stages. First, a brief overview of the development of SI system uptake in Japan and China is presented. Second, the differences in amalgamated dwelling between China and Japan are compared by three determinants. Basically, each determinant has an effect on the design of SI housing. Third, the corresponding design trend of SI housing in China is proposed based on the analysis of the differences.

4. Development of SI System

4.1 Japan
SI system came from SAR Theory proposed by Professor Habraken. However, SAR theory was really
absorbed and gradually became SI theory in Japan. Japan developed Kodan Experimental Housing Project (KEP) in 1973, then establishment the New Plan System (NPS) in 1976 and the Century Housing System (CHS) in 1980. Based on previous research and practice, the Kikou Skeleton Infill (KSI) housing developed in 1998. In the 21st Century, Japan has comprehensively promoted and implemented the KSI housing technology in the public housing. Japanese SI system has a sophisticated system including 3 parts, which are durable support systems, variable interior systems, and standardized component systems.

In 2009, Japanese government promoted a new law called “The Act for Promotion of Long-Life Quality Housing”. Long-Life Quality Housing continues the concept of SI housing, but it has not only paid attention to the longevity design of the building, but also has paid attention to the relationship among buildings and people and city. According to the statistics of Ministry of land, Infrastructure, Transport and Tourism in Japan 915,617 houses been certified by Long-Life Quality Housing (Fig. 1.), 2.26% of which are amalgamated dwellings.

4.2 China
Since 1999, a real estate company named Vanke started has introduced SI technology from Japan. The company adopting SI technology with the Chinese construction technology and put forward the Vanke Skeleton Infill (VSI) system. But up to now, Vanke have not built one project with fully application of VSI technology. Which indicates that under the present circumstances, SI system has not been fully integrated into Chinese .industrial residential system.

On the other hand, Chinese government started to develop SI housing in 2006. Three years later, the showroom of CSI (China Skeleton Infill) housing called “Tomorrow's Home No.2” was built in 9th China International Exhibition On Housing in 2010. Also in 2010, the first CSI project was built in Beijing . Then there were two projects built in Beijing and Shanghai in 2015 (Table 1.). The design and construction of CSI projects built in China are under the guidance of a Japanese company. All three projects are experimental and sponsored by government.

| Designer              | Name                      | Location       | Area        | Year  |
|-----------------------|---------------------------|----------------|-------------|-------|
| CADG/ichiura Housing &Planning | Hejin Apartment          | Beijing        | 77,848 ㎡   | 2010  |
| CBS/ichiura Housing &Planning   | Guangheyuanzhu Public Apartment | Beijing        | 16,949 ㎡   | 2015  |
| CBS/ichiura Housing & Planning      | Building 11 of William Mansion | Shanghai   | 11,909 ㎡   | 2015  |

4.3 Summary
Statistics on quantity of SI housing shows that after years of practice and exploration, a mature system for SI housing has been established in Japan. Which includes relevant regulations, industrial structures, supply chain system and technical system. Compare with Japan, SI housing is a relatively new thing in China, which has begun only a few years ago. The existing projects are imitating
Japanese models without localization transformation, making them more like experiment projects. In order to develop SI housing in China, the difference in key determinant between two countries should be revealed. The determinants are explored below.

5. Discussion

5.1 Housing ownership model
After years of development in Japan, the housing ownership models has been already a mature system. For the amalgamated dwelling in SI system, there is two-stage supply mode. The two-stage supply mode takes 30 years as a cycle. With 60 years after the purchase of the dwelling, the dwelling will transform to a renting residence.

China is a country under the public ownership of land. The ownership of a residence is divided into 2 parts, which are the ownership of the land and the ownership of the dwelling unit. For commodity dwelling, customers own the permanent ownership of the dwelling and the ownership of the land for 70 years. For public residence, the ownership of the dwelling and lands all belongs to the government. In addition, according to the current regulation of China, the term of lease for public residence is generally no more than 5 years.

5.2. Residential scale
The private house is the mainstream of living (Fig. 1) in Japan, while situation is quite different in China, where the vast majority of urban population are living in amalgamated dwelling currently. Obviously, Chinese need more choices on dwelling areas than Japanese. In Japan, over 70% dwelling areas are between 65 m²-80 m², and the SI amalgamated dwelling also follows such design habits. While in China the resident’s demand is far more than this interval. According to the data from National Bureau of Statistics of China, the most popular area interval is 90 m² to 144 m² in Chinese algorithm (Fig. 2).

In Chinese dwelling unit, the dimension of the functional room is 20%-30% bigger than that in Japan (Zhu, 2008). Which means that even in terms of the same unit type, the area of main functional room in China, such as living room, bedroom and dining room is much bigger than that in Japan. Moreover, the area distribution in dwelling unit is different between China and Japan. The area of bathroom, storage space and indoor traffic space have accounted for a larger percentage of total areas in Japan.

![Fig.2 Quantity Sold and Proportion of 90 m² to 144 m² dwelling, 2012-2016](image)

5.3. Residential Form
The most common form of amalgamated dwelling in Japanese SI system is what we called gallery
apartments due to Japanese fire regulation. But the gallery apartments are rarely built in China except apartments for students. The most common form of amalgamated dwelling in China is the core apartment (Fig. 3.). Besides, the building height of majority Chinese amalgamated dwellings are over 50 meters, while the opposite situation appears in Japan. Hence, that it has caused different structure designs in two countries.

Whether in Japan and China, the most common residential form in amalgamated dwelling is LDK type, which type has been approved by the resident in two countries. Although in SI system the residential form is variable, the basic functions in a dwelling unit are stationary, including kitchens, dining rooms, living rooms, bedrooms and bathrooms. While because of the different regulation, the combinations of function rooms are different. The Chinese regulation about residential design the living rooms, the bedrooms and kitchens have regulated that windows are supposed to be open to the outside and bathroom is not allowed to arrange upstairs in the kitchens, dining rooms, living rooms and bedrooms (Table 2).

Table 2. The Relevant Regulation of Dwelling Function Space in China

| Relevant regulation |
|---------------------|
| Living room         | Needs daylights and natural ventilation |
| Bedroom             | Needs daylights and natural ventilation |
| Kitchen             | Needs daylights, natural ventilation and near the vestibule |
| Bathroom            | Do not allowed to arrange upstairs in the kitchens, dining rooms, living rooms and bedrooms |
6. Conclusions
This paper illustrates the determinants get to affect the design of SI housing and clarifies the differences of each determinant between China and Japan. The effects of these differences could be summarized as follows:

At the moment, China has not set up relevant regulations about long-term rental residence, therefore, very few people rent one house or apartment for a long time. Although China has already built a public apartment which used SI technique, the apartment is hard to realize its true value. On the other hand, the cost of renovation for every short-term tenant is too high to implement. Under this circumstance, the best development model for SI housing in China is the commodity dwelling because a long and stable life style corresponds the real value for the SI housing.

Commodity dwelling is a product matching diversified market needs. According to the data (Fig. 2), in the past five years the area between 90 \( m^2 \) to 144 \( m^2 \) has been increasingly popular in China. Hence, the mainstream area of CSI dwelling unit is supposed be big enough to accommodate 3LDK apartment.

Finally, the regulation about residence design in China limits the variability of the dwelling unit. In the CSI dwelling has been built, the position of the kitchen and the bathroom is invariable. Which reduces the variability of dwelling units considerably. Therefore, the design of CSI dwelling needs classification of each function space, and there is invariable function space, semi-variable function space and variable function space (Fig. 4). Elaborate classification and designs will enhance the diversity of CSI dwelling.

In China, whether industrial residential system or SI system is far from being called a mature system. The design of CSI dwelling still needs further study, but it is clear that a successful industrial residential system is not only based on the technical system. There is a lot relevant determinants that can affect the development industrial residential system, and some of them such as industry structure or supply chain still need further research.

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