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Exploring the challenges to industrialised residential building in China

Abstract

Industrialised building (IB) is considered by many to have an important role to play in China's residential construction industry due to its potential for improved quality, productivity, efficiency, safety and sustainability. It is surprising, therefore, that although a large number of construction programs have been completed in the country in recent years, very few have been built in this manner. Quite why this situation exists is unknown. The well-known problems with IB, such as the constraints placed on designer freedom, may be the cause. It is equally possible that, as is typical with developing countries such as China, cost or government issues dominate. On the other hand, in comparison with other countries, the construction industry in China has been widely criticised for its lack of modernity. Either way, there is an urgent need to assess and understand the hindrances to the adoption of IB in residential construction in order to identify what corrective measures, if any, need to be taken.

Towards this end, we first identify a set of critical factors (CFs) for assessing the hindrances to IB adoption in China. This involves the analysis of research data collected by a questionnaire survey of experienced housing developers and professionals working in China's construction industry sector. Fuzzy set theory is used in the selection of the CFs. These CFs comprise, in rank order: higher initial cost; lack of skilled labour in IB; manufacturing capability and involvement issues and product quality problems; lack of supply chain; lack of codes and standards; and lack of government incentives, directives and promotion. The establishment of the CFs provides a basis for local construction sectors to better equip themselves for future implementation of IB. The findings also indicate a current need for formulating improved policies and strategies to encourage the further development of IB in China at present.

Keywords:

Industrialised building; residential construction, critical assessment factors, China, fuzzy set theory.

Introduction

Industrialised Building (IB), where construction components are manufactured in a controlled environment, either at site or off site, placed and assembled into construction works, is considered by many to be a key for improving the construction industry (e.g. Hampson & Brandon, 2004; Cook, 2005) and there have been many studies regarding the implementation of the IB approach and its potential. For example, although some maintain that IB approach is comparatively more expensive than conventional construction methods (e.g. Birkbeck & Scoones, 2005), many studies find that project cost savings due to IB implementation has substantially increased over time (e.g. Goodier & Gibb, 2007; Gibb & Isack, 2003). Recent work has also highlighted the potentially positive role of IB in the introduction of green construction (Jaillon & Poon, 2008; Zhang & Skitmore, 2012).

The industrialisation of residential building construction is one of the most significant developments in recent years, having reached over 50% in developed countries by 2010 (Jia, 2010). Unsurprisingly, therefore, industrialised housing is increasingly becoming a major alternative form of construction in China (Pan, 2007) and the Chinese government has started proactively to promote the implementation IB to meet rapidly growing housing needs. However, while a consensus exists in favour of industrialisation due to its established potential for improving the quality and productivity of building projects, progress in implementation is relatively slow, with under 10% of completed domestic housing projects in the past 10 years being industrialised (Fan, 2010). Even for the China Vanke Group, one of China's largest real estate developers, the level of industrialisation reached only 20% (Qin, 2011).

To date, very few studies have investigated the constraints involved in adopting IB in China. As a starting point, therefore, we seek to bridge the knowledge gap concerning the hindrances involved by identifying and examining the critical factors (CFs) needed to assess the constraints on industrialised building. An historical review of the development of IB is first conducted. This is followed by initial identification of a checklist of the CFs needed. Next, a questionnaire survey of experienced housing developers and professionals working in China's construction industry is analysed. Then, through the application of fuzzy set theory, several CFs are selected to evaluate the constraints involved. Finally, important implications and useful directions for future research are identified and discussed.

Literature review

IB, with its stated aim of raising efficiency by rationalising the construction process through the adoption of scientific approaches, is considered by many to have begun in the late 1950s in Japan and adopted later in Europe and North America (Gann, 2010). Although developing at the end of a continuum of possible processes that take different paths in different countries, several specific characteristics reflect IB development in developed countries. Of these, 'standardisation' (Gann, 1996; Lessing et al., 2005), 'prefabrication' (Dawood, 1996; Gibb, 2001) and 'system building' (Finnimore, 1989; Gann, 1996) are three underpinning attributes that portray the essence of industrialised buildings as follows:

- *Standardisation:* the prerequisite for the factory production of components (Gann, 1996). After World War II, 'modular co-ordination in building' first aroused the attention of European and North American countries. Then, in the 1960s, the United Nations proposed its 'building modular coordination', setting up standardised criteria for examining component specifications such as performance, structure, tolerance and installation (Milton, 1980).
- *Prefabrication*: involving factory-built components that are assembled on-site to increase the speed of construction and to reduce costs. These components generally comprise two types - those produced directly off-site without knowing the design of the building, and those produced for a specific building with prior knowledge of its design (Gann, 1996).
- *Systems building*: links the prefabricated components with manufactures, involves construction sequencing and a streamlined off-site construction technology service system. System building relies on a well-coordinated development scenario where designers (architects and engineers) work together. For example, there were more than 100 modular factories in America in the 1970s, forming an integrated, independent industry from design to production. In addition, site handling, site clean up and the demolition of buildings may be commissioned to be undertaken by a specialist organisation (Wang, 2006).

Of these attributes, the first two are the most common. Japan's industrialisation housing, for example, began when the need for homes increased dramatically, leaving the industry with insufficient construction personnel and skilled workers to satisfy demand. In order to simplify site construction and improve the quality and efficiency of the residential product, many building components were standardised for mass production and prefabrication buildings were produced on a large scale (Barlow et al., 2003). As a result, the major building forms in this period included box-style and modular in addition to large residential wall forms. Also, during the 1970s, several large construction enterprise groups, such as the Daiwa House Group, entered the market, contributing to the maturity of the housing industry at that time. By the 1990s, IB accounted for 25%-28% of the total number of residential houses completed, with 1,418 components having gained 'good residential parts' certification. In Asian counties other than Japan, such as Singapore, the IB approach was introduced in the early 1980s, involving several prefabrication systems developed by local and overseas contractors (Wong & Yeh, 1985).

In Europe, France was one of the world's earliest countries to implement IB. From the 1950s to 1970s, the 'first generation of building industrialisation' was established, characterised by fully assembled prefabricated panels and an instrumental template situ process (Pan et al., 2007). This was followed in the 1970s by the 'second generation of building industrialisation' to meet the increasing needs of the construction market and characterised by the transitional development of common components and equipment. Later, in 1996, high precast levels were reported in Denmark (43%), the Netherlands (40%) and Sweden and Germany (31%) (Jaillon & Poon, 2009).

IB is very popular in North American countries, where the development of standardisation and system building is very advanced. As residential construction in this region was affected little by World War II, the European large-scale prefabricated approach was not followed, but instead a rather individualised and diversified residential style became the focus. Most of the houses are low-level wooden structures built in the suburbs, designed to accommodate the requirements or specific tastes of homeowners (Fan, 2010). The market then provides the materials, components or any other parts needed. These standardised, serialised component parts are either purchased and installed by the owners themselves or commissioned from contractors on site (Friedmana & Cammalleria, 1993).

The Malaysia Construction Industry Development Board defines IB as a construction technique in which components are manufactured in a controlled environment (on or off site), transported, positioned and installed into a structure with minimal additional site works (CIDB, 2003). This is considered to be of national importance in providing an answer to Malaysia's housing shortage (Badir et al., 2002) and, since 2003, the government has embarked on the program to promote its by insisting that all public projects must contain 70% Industrialised Building System components (Chuan & Rashid, 2011). However, the System needs a much higher initial capital investment than does the conventional system due to the need to construct production facilities and the high cost of training labour (Badir et al., 2002).

IB development in China has gone through a long and complicated three-stage process as described in the next section.

IB in China

Initial development stage: 1950s-1970s

Research and use of precast concrete structures in China goes back to the 1950s. However, it was only in the early 1970s that prefabricated housing technologies were attempted - mainly focused on learning from the former Soviet Union's large boardroom building technique (Wang, 2006). This kind of building technique enabled the former Soviet Union's central construction agencies to prepare several standard architectural designs to be used by modern factories capable of mass producing precast concrete components ("large blocks") and a series of standard designs for apartment houses to be built by the large panel method (McCutcheon, 1989).

During this period, the Government put forward its "three transformations" of design standardisation, factory production of components and parts, construction mechanisation and wall reform, as a move to ultimately realise the industrialisation goal of high-quality, high-speed, high-efficiency and low-cost construction (Chu, 2009). However, the boardroom method at that time had many serious problems. In addition to poor earthquake resistance, the structure was not waterproof, with poor quality sealants causing large areas of water seepage two or three years after construction completion. Moreover, no thermal, heat or sound insulation measures were considered, bringing a great deal of inconvenience to the tenants. As a result, prefabricated technology in China gradually fell into disuse (Ding & Zhao, 2003).

Recovery development stage: 1980s-early 2000s

During the mid-1980s, the government began to promote large-scale housing development. In order to meet the increased demands involved, the IB concept was once again pursued, eventually resulting in the introduction of "industrialised housing" towards the end of the 1980s (Chu, 2009). However, after entering a 'golden era' of booming housing development in 1990s, the use of IB was again almost stagnant. The success of housing development during this period was based mainly on the developer's ability to obtain the resources of capital and land needed, which resulted in the neglect of IB technological innovation.

By 1995, noting lessons learned at home and abroad, policy makers and relevant professionals in China had begun to realise the importance of IB, particularly for residential construction, and the need to continue to develop the industrialisation approach for the country's future development (Zhai et al., 2013). In 1998, the Ministry of Housing Industrialisation Promotion Centre was established and, in 1999, the eight ministries of the State Council issued the official document, *To Improve Residential Housing's Quality by Way of Industrialisation and Modernisation* (State Council, 1998). Following this, with the assistance of experts from the recently instituted Japan International Cooperation Agency project, several technical standard documents (including the *Commercial Housing Performance Indicator System* and *National Demonstration Project Construction Technical Points*) were gradually introduced into China with the benefit of Japan's more mature approach (Chu, 2009). As a direct result of these initiatives, China's residential house performance certification system was established.

Expansion development stage: middle 2000s-now

With the sustained and rapid development of the national economy, growing labour costs and an increasing demand for energy saving and environmental protection, the use of architectural precast concrete has gradually been increasing, with an associated expansion of and IB development since the middle 2000s. The government has established a list of IB standards, providing technical support for IB practices, and a preliminary IB building materials and standardised production system has been instigated (Zhang & Skitmore, 2012). In particular, an increasing number of large integrated build-operate housing industry groups, such as the Vanke Corporation and Nantong Construction Engineering General Contracting Enterprise, have entered the market. In 2005, the Vanke Corporation's Beijing group completed the R&D of their successful "prefabricated shear wall structure system". Next, the Nantong Construction Engineering General Contracting Enterprise introduced the innovative "whole prefabricated shear wall structure (NPC) system" (Yang et al., 2012). Following this was the “composite board assembly monolithic concrete structure system” created by the West Weide precast concrete company; the “prefabricated frame structure” by the Taiwan Ruentex Group; and the “prefabricated reinforced concrete shear wall structural system” by the Heilongjiang Yuhui Construction Group - all successfully implemented in real-life construction projects.

The development and introduction of these IB technologies is further illustrated from a summary of the development stages experienced over the last decade by China Vanke, one of the country’s largest developer/constructor behemoths (Mao, 2010; Qin, 2011).

- As early as 2003, China Vanke initiated the standardised residential movement by introducing a series of internal control standards, including its “Residential use standards” and “Residential performance standards”. These not only standardised the composition of multi-storey apartments, scenario houses and residential quarters within the group, but also involved the R&D work needed for the design and development of standardised parts and consequent development of the Vanke standardised parts library.
- In 2004, the group started implementing their industrialised housing system on the basis of standardised factory work, establishing a factory centre in Dongguan in the Guangdong Province. Work also began on furthering their R&D with the Vanke industrialised housing brand.
- In 2007, they completed the construction of 150,000 square meters of industrialised housing in China.
- In 2008, started nine residential industrialisation projects, completing more than 600,000 square meters of work.
- From 2009 to present, Vanke have continued their construction of IB projects in several pilot cities to prepare sufficient technical, resources and personnel for large-scale IB construction in China. It is anticipated that they will build around 1.2 million square meters of industrialised housing in the near future (Qin, 2011).

Over the last 25 years, cities in China have experienced a rapid urbanisation process with an increase of the urbanisation rate from 17.4% in 1978 to 51.27% in 2011 (National Bureau of Statistics of China 2012). The construction industry has also developing rapidly, creating many problems including low productivity and poor environmental performance. In contrast with IB’s characterised high degree of mechanisation, traditional construction methods are dominated by labour-intensive approaches involving the use of considerable onsite labour. Recent labour shortages in the industry have resulted in insufficient workers being available to undertake traditional construction projects (The China Real Time Report, 2010), with resulting delays in production and delivery time - challenges that are well suited to be met by IB (Nawi & Nor, 2011). In anticipation of this situation continuing or worsening, IB has therefore been made a high priority in order to survive the challenges ahead, with the Chinese government proactively promoting its implementation throughout the country. Despite this, however, few Chinese research institutes and housing developers have adopted IB, and relatively few buildings have been constructed with IB methods (Liu & Ying, 2009). The reasons for this unexpected situation are not clear, hence the need for further studies.

Research method

To better understand the issues involved, research data were collected and analysed in two stages: (1) to provide an initial list of CFs affecting the take up of IB in the China housing industry; and (2) to measure the extent of the effect of each listed CF.

Stage 1: list of CFs

The various constraints identified in the literature that affect IB practices mainly concern the initial costs involved and lack of professional resources needed, and are typically concerned with issues surrounding prefabrication and off-site production (Blismas *et al*., 2006). A comprehensive initial list was made from existing literature (e.g. Chiang et al, 2006; Tam et al., 2007; Jaillon et al., 2009). This was then refined through a series of interviews with a variety of experts, including five from universities, seven government officials and nine employed in construction and real estate enterprises - all with extensive practical experience in the China housing construction industry. As a result, 16 CFs were finally chosen, summarised in Table 1.

Stage 2: importance of CFs

The data for analysing the importance of the CFs was collected through a constructive questionnaire survey. A number of preceding studies have used a questionnaire survey as an effective means of collecting primary data of industry perspectives concerning the use of IB (Zhai et al., 2013). Being concerned solely with the 16 factors identified in Stage 1, a simple questionnaire scoring system was sufficient to obtain respondents' perceptions while ensuring a sufficiently large size sample for subsequent analysis. The questionnaire comprised two parts: (a) questions relating to the respondents' background; and (b) their rating of the influence of each listed CF in restricting the use of IB. In view of the subjective nature of the responses, a coarse graded scoring system was sufficient to capture the qualitative information involved and a Likert scale was used, delimited from 1 (little influence) to 5 (highly influential)

The survey was conducted of a sample of Chinese practitioners with experience of IB projects. Initially, the population of this study comprised of two stratums: academic/professionals doing research in IB and practitioners/project managers working on IB projects in China's construction industry. The sampling frame for the academic/professionals was the membership list of the Chinese Research Institute of Construction Management, from which 79 academics/professionals were randomly selected. The sampling frame for practitioners/project managers was a composite listing from the construction practitioners with experiences in IB projects in China, from which a total of 46 practitioners were nominated. A valid contact list of the practitioners was obtained with the help of a collaborative organisation in Shanghai. The two lists served as a representative population to which to distribute the survey.

Letters and e-mails were then sent to members of this group inviting them to participate in the survey. This resulted in 67 positive responses whereupon the questionnaire was distributed by e-mail or post. To increase the sample size, a 'snowball' sampling method was also used, in which the 67 respondents were invited to help distribute the questionnaire to their colleagues and business partners whom they knew to be experienced in IB. Despite the disadvantages of 'snowball' sampling, it has merit in providing a means of locating specific construction IB practitioners/experts. As more relationships are built through mutual association, more connections and information sharing can take place through those new relationships.

In this way, a total of 155 questionnaires were dispatched via e-mail and conventional post in June 2011. This was followed-up by a subsequent reminder letter sent to the respondents who had not immediately returned the questionnaire. Finally, 89 fully completed questionnaires were received at a response rate of 57%. Of these, 47 (53%) were from business practitioners and 42 (47%) from academics/professionals. The respondents' basic information (names, education qualifications, working experience, etc.) were compiled and summarised (Table 2).

After an Analysis of Variance to ensure the homogeneity of the respondents' opinions, relative significance values were obtained from the mean or covariance values of the respondents' scores. A fuzzy set theoretic method was then developed and used to accommodate the uncertainty involved and rank order the CFs in terms of their perceived influence. Details of these two analyses and their results are provided in the next section.

Results

Homogeneity of responses

The means and standard deviations of the CF scores are shown in Table 3. These can be used to gauge the average opinions and differences in judgment of the relative influence of factors on IB take up. For example, CF_1 represents the factor "Lack of government incentive, directive and promotion", and has an overall mean score of 3.44 with standard deviation (SD) of 0.78. Within this, the business practitioner group provided a CF_1 mean score of 3.04 (0.66 SD), while the University academics group's CF_1 mean score is 3.88 (0.67 SD) – indicating a higher mean score for the sample of academics/professionals than the business practitioners.

An Analysis of Variance (ANOVA) helps to appreciate the significance of overall differences between the business practitioner and university academic groups. For the ANOVA test, a probability above $p>0.05$ is taken to indicate that the difference of opinions between the groups is insufficient to be regarded as any more than a chance result, hence the groups are homogeneous. In the event, the ANOVA probability values for four of the indicators are below 0.05, indicating that the homogeneity assumption is likely to be violated in this case. Thus, the two groups are treated separately in further analysis.

Identifying the CFs

Let $\tilde{A}$ designate a fuzzy set of CFs, such that

$$\tilde{A} = \mu_{\tilde{A}}(x_{11})/x_{11} + \mu_{\tilde{A}}(x_{12})/x_{12} + ... = \sum_{i=1}^{n}\sum_{j=1}^{m}\mu_{\tilde{A}}(x_{ij})/x_{ij} \qquad (1)$$

where x_{ij} is an indicator listed in Table 1; n denotes the number of categories of indicators (two in this study); and m is the number of indicators under each category. $\mu_{\tilde{A}}(x_{ij})$ denotes the degree of membership of x_{ij} in the fuzzy set $\tilde{A}$, assuming a value within the interval between 0 and 1, namely $\mu_{\tilde{A}}(x_{ij}) \in [0,1]$. Note that the symbols + and / do not stand for 'plus' and 'divided by', but are just symbols in a fuzzy set. / in $\mu_{\tilde{A}}(x_{ij})/x_{ij}$ indicates the relation that the degree of membership of x_{ij} is $\mu_{\tilde{A}}(x_{ij})$, and + can be read as a logical operator 'and'.

In applying fuzzy set theory, the membership degree of an indicator in the fuzzy set is used to identify whether or not the indicator is critical. This mitigates the weakness of the traditional cut-off value method for identifying critical assessment indicators. As the influence of a specific indicator is scored between 1 and 5, the score of 3 can be considered as a demarcation scale for differentiating between what is critical and what is not critical. It is therefore legitimate to consider that the probability of indicator being critical is less than 50% if the mean value of this indicator is less than 3. Hence, referring to a specific indicator, only a scale value above 3 will be further considered for analysing the significance of the indicator.

Based on fuzzy set theory, the probability for an indicator to be included in the CFs fuzzy set is the degree of membership of the indicator in the CFs fuzzy set (Zimmermann, 2001). Now, the degree of membership $\mu_{\tilde{A}}(x_{ij})$ can be described as

$$\mu_{\tilde{A}}(x_{ij}) = \int_{3}^{5} f(V_{x_{ij}}) \tag{2}$$

where $V_{x_{ij}}$ is a particular score value between 3 and 5 for the indicator x_{ij} and $f(V_{x_{ij}})$ represents the frequency of the occurrence for the indicator x_{ij}. The degree of membership $\mu_{\tilde{A}}(x_{ij})$ is calculated by summing the frequency $f(V_{x_{ij}})$, where x_{ij} assumes a scale value between 3 and 5.

Furthermore, as the data used for analysis comes from two groups (business practitioners and university academics), there are two CF fuzzy sets, represented by $\tilde{A}_B$, and $\tilde{A}_U$, accompanied by two sets of membership values $\mu_{\tilde{A}_B}$ and $\mu_{\tilde{A}_U}$. According to (2), the membership values for $\mu_{\tilde{A}_B}$ and $\mu_{\tilde{A}_U}$ can be calculated, the results of which are shown in Table 4.

According to the definition of the union operator in fuzzy theory (Yager 1980), an integrated CFs fuzzy set can be obtained from

$$\tilde{A} = \tilde{A}_B \cup \tilde{A}_U = \left\{x, \mu_{\tilde{A}_B \cup \tilde{A}_U}\right\} \tag{3}$$

where

$$\mu_{\tilde{A}_B \cup \tilde{A}_U} = \mu_{\tilde{A}}(x_{ij}) = \min\left\{1, [\mu_{\tilde{A}_B}(x)^p + \mu_{\tilde{A}_U}(x)^p]^{1/p}\right\}, p \geq 1 \tag{4}$$

where p denotes the number of factors (16 in this study). By applying the data of $\mu_{\tilde{A}_B}$ and $\mu_{\tilde{A}_U}$ in Table 4, the integrated results $\mu_{\tilde{A}}(x_{ij})$ are obtained based on (4), and tabulated in the last column of Table 4.

To identify the CFs from the results in Table 4, the λ-cut set approach is adopted. By applying a benchmark value λ, the indicator x_{ij} is considered a critical assessment indicator if its degree of membership exceeds the preset threshold value λ. The benchmark value λ determines the number of indicators in the CFs set. For example, if λ=0, all the indicators belong to the CFs set, while if λ=1, there will be fewer or even none of the indicators in the CFs set. Notwithstanding, λ=0.85, is a commonly used threshold in fuzzy set theory for identifying critical factors (e.g. Abunawass *et al.* 1998; Uysal and Yarman-Vural 2003; Shen *et al.* 2011). Adopting this criterion in conjunction with Table 4 results in CF$_1$, CF$_2$, CF$_3$, CF$_5$, CF$_6$, and CF$_8$ being identified as the appropriate CFs involved.

Discussion

It is important to understand the implications of these six CFs (CF$_1$, CF$_2$, CF$_3$, CF$_5$, CF$_6$, and CF$_8$) as they may help business professionals and local government find ways of overcoming the major barriers to IB in practice. Ranking the six CFs by the degree of membership in descending order of importance gives:

1. Higher initial cost CF$_6$ (with membership degree λ of 1.00);
2. Lack of skilled labours in IB CF$_3$ (with membership degree λ of 0.961);

3. Manufacturing capability, involvement issues and product quality problems CF_2 (with membership degree λ of 0.944);
4. Lack of supply chain CF_5 (with membership degree λ of 0.943);
5. Lack of code and standard CF_8 (with membership degree λ of 0.930);
6. Lack of government incentive, directive and promotion CF_1 (with membership degree λ of 0.906).

Starting with the most important of these, the following section highlights the hindrances involved for further discussion.

1. CF_6-Higher initial cost

A high initial cost is considered the most significant barrier to the use of IB. It is assumed by many researchers and practitioners that economic parameters are usually a very important component of the decision-making process when selecting the optimal construction method (Zhai et al., 2013). Compared with traditional construction methods, the initial cost of IB includes the cost of constructing the manufacturing unit, casting beds, cost of precast components and support machinery etc. Precast components involving steel formwork, for example, have a production cost that is much higher than that of wood. According to Wangshi, the Chairman of China Vanke, the production cost for IB is 350-500 RMB per m^2 more than traditional housing in China. All else being equal, therefore, economies of scale of at least 350-500 RMB per m^2 are needed initially for IB to be economically viable for China Vanke. In an industry not known for its economies of scale (Runeson & de Valance, 2009), this is likely to be a major challenge.

Another practical factor that has aggravated the cost issue in China is its unprecedentedly high sales price of housing. On one hand, this has resulted in very low housing vacancy rates, while on the other hand, the high sales price has reduced housing developers' motivation to pay extra the extra R&D and production costs associated with IB. In addition, homebuyers in China do not currently have a mature or clear understanding of IB, which makes it more difficult for developers or contractors to invest their human and monetary resources in IB R&D and production.

2. CF_3- Lack of skilled labour in IB

The lack of skilled labour in IB is considered the second most important barrier to IB in China. One reason is that the whole process of IB, from the initial production of prefabricated components to their installation, is very complicated. This is because all the components involved are manufactured in advance, and need to be assembled and installed precisely in accordance with the manufacturer's instructions. It is often very difficult to remedy mistakes and therefore necessary for construction companies to establish sound organisational and quality assurance systems to ensure that workers complete the process accurately and according to schedule.

In addition, IB is characterised by a high degree of mechanisation, with less labour but increased precision, necessitating the presence of sufficiently highly qualified construction workers. However, the opportunities for professional experience and training are very limited in China. Its construction industry is still quite primitive and heavily dependent on manual work (Xiong & Liu, 2010). In most cases, construction work is the preferred occupation of migrant workers, as little advance training is needed. Low construction prices in China make it hard for construction companies to provide the investment of money and time necessary for crucial training. This was evidenced in 2009, when one of Vanke's IB residential projects in

Shanghai was reported by the media to have wall cracks, leakage and seepage problems. Although the homeowners involved criticised the industrialised housing technology itself, the real reason appears to be in the misapplication of the technology due to the lack of professional experience of the construction operatives. Clearly, it would seem that a greater emphasis on construction personnel training is an urgent and critical issue now.

3. *CF_2-Manufacturing capability and product quality problems*

As is well known, most IB construction work is carried out in the design and manufacturing stages. Design accuracy and the manufacturing optimisation of prefabricated products has become a major obstacle in developing IB in China. As they are different from the usual off-the-shelf products, IB products create special challenges for manufacturers. For example, it is difficult to find a domestic building mould manufacturer in China to meet the individual needs of customers' building mould, stairs, walls, beams and other building blocks of production. Therefore, housing developers, in addition to contractors, have not only to produce the building blocks as manufacturers, but also to buy the building blocks as purchasers. This stretching of the production chain is likely to increase overall cost. On the other hand, product quality problems are also considered one of the major obstacles in developing IB (Arif & Egbu, 2010). Defective connections or deformations usually appear in precast elements, resulting in cracks and water leakages and creating additional maintenance problems in the long run. Other quality problems exist such as wall insulation cracking, pipe leakage in the kitchen and toilet, and poor sound insulation, all of which have created many disputes between buyers and developers.

4. *CF5-Lack of supply chain*

One of the bottlenecks in China's housing industry is the lack of an efficient supply chain. The current status of the construction industry can be described as a diverse range of fragmented trades that are extremely difficult to coordinate due to the absence of a supply chain (Zhai et al., 2013). Compared with the relatively high level of IB construction in the USA and Japan, China lacks a mature set of building systems (such as wood structures and light steel construction systems) and matching construction technologies. Although there are many individual construction technologies, industrial supply chains, supporting technologies and large-scale production systems are missing. The production of construction parts needs to be standardised, serialised, scaled and universalised to gradually form the IB supply chain system needed in the longer term. Through the establishment of an 'elimination, certification and recommendation system' for domestic components and parts, the existing non-compliant modulus product can be gradually abandoned and housing products upgraded, so that the housing downstream can move towards a universal supply chain. For example, it is difficult in practice to find a mature supply chain for light steel construction systems in China.

5. *CF_8-Lack of codes and standards*

The lack of universal technical standards is another hindrance to the development of IB in China. As yet, there are no industry peremptory norms for IB, except for those pilots who have participated in setting up their own standards. It is therefore difficult to find any national uniform standards for the combination of space and load-bearing systems through to small components within rooms. Problems such as a single species of IB components and the low level of product integration make it difficult for new residential building systems to find matched supporting parts (Taylor, 2009). For example, the structure of large bays, large span floors and wall materials cannot usually be matched with the design of modern residential buildings. This non-standardised form of production not only leads to the duplication of design and the repetition of construction waste, but also hinders the further development of prefabricated components in the factory, construction mechanisation and assembly.

The establishment of a standardisation system is considered the basis of IB development. One of the important means of standardisation is to establish a modulus system, as it is only by establishing a residential system with components as well as the fittings of the modulus harmonised system that an IB standard system can be finally instituted. With the IB standard system, professionals involved in IB projects can select matched components by complying with the requirements of the relevant modulus. In this way, the composition of IB components can be ensured to be according to the principle of standardised production, so that a variety of housing parts can be accurately installed at the specified site. In addition, all the parts can be interchangeable, which helps the manufacturers and contractors plan production and on-site construction to obtain economies of scale. Thus, the efficiency of construction is improved, ensuring construction quality and reduced cost.

6. CF_1-Lack of government incentives, directives and promotion

At the current time, there is a lack of government incentive and promotion strategies in driving IB development. There is a perception that government, as mentor, supervisor and facilitator, should to develop a reasonable policy to drive IB into a healthy state. This CF reflects the view that there is an insufficiency of proactive incentive policies, regulatory mechanisms and efficient government supervision systems in generating enthusiasm for the development of IB. This lack of government promotion has caused some consumer misconceptions concerning housing industrialisation. As is echoed by Zhai et al. (2013), without adequate promotion and incentives provided by the Chinese government it appears the public perception of construction methods including offsite production remains defensive. In the 1980s, China’s prefabricated housing program suffered from many quality problems, which has left customers with the negative impression that “industrialised housing means that quality is not guaranteed”. The current Chinese government’s lack of IB promotion has not yet changed this adverse public impression. In addition, although there are many IB pilot projects in China, there is little local policy support for these projects. For example, there are no tax relief measures or strategies for municipal construction costs to encourage the implementation of water treatment systems in many energy-saving demonstration areas. As a result, and in view of the initial costs involved, companies have little inspiration to embrace IB. One solution might be to legalise the modular system in China. As is well known, Denmark was the world’s first country to have its modulus system legalised and the International Organization for Standardization ISO modular coordination standard is therefore based on the Danish standard. Without an official legal system or strong government support, many developers and contractors hesitate to take a lead in furthering the progress of IB.

Conclusions

With its potential for capitalising on the strengths of the manufacturing industry, IB has been considered by many to be the future of the construction industry worldwide. However, unlike the successes of countries such as Japan and the USA, IB has yet to make an impact in China. Despite the large number of construction programs that have been completed, very few have been built in such a manner. It is unknown why this is the case.

To uncover the perceived reasons for lack of IB take up in China, we first identified the set of CFs concerned. Fuzzy set theory was then used to select six CFs from research data collected by a questionnaire survey of experienced Chinese housing developers and construction industry professionals. These CFs comprise, in rank order: high initial costs; lack of skilled labour in IB; manufacturing capability and involvement issues and product quality problems; lack of supply chain; lack of codes and standards; and lack of government incentives, directives and promotion.

The establishment of the CFs provides a basis for local construction sectors to better equip themselves to implement IB. As might be expected from a group of respondents in a country where state support has been a common feature in transitioning from state run to free market industries, the findings also reflect industry's desire for improved government policies and strategies to encourage further IB in China. Similarly, government involvement in the form of subsidies or incentives is sought to support the necessary investment involved until production levels reach the point where economies of scale due to mass production result in viable market prices of components and parts. Likewise, a similar argument can also be made for government support in reskilling the labour force, increasing manufacturing capability and providing codes and standards, particularly where issues of quality are involved. With the injection of public funds needed, it is expected that industry itself would provide the enterprise necessary for the creation of the necessary supply chains.

The provision of a paternal government approach to start-up investment such as this would not be new to China - China's wind world leading power industry being an outstanding example of the outstanding benefits achieved by early government industry protection and control, then support and final replacement by the open market. This latter point raises interesting issues concerning the relatively recent public-private collaboration evidenced in regions of China such as Shanghai, where the private sector (albeit predominantly overseas investors) has made significant contributions to the urban development of area. How such associations will continue to develop in the future is unknown. However, despite there being no expectations of overseas involvement at this stage, it is clear that this aspect could have a substantial impact on China’s IB activities. Further research may be able to offer some suggestions.

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Table 1: A checklist of CFs for investigating the constraints of IB

Code	Constraints	Key references
CF_1	Lack of government incentives, directives and promotion	Kamar *et al* (2009); Nawi *et al* (2011); Haron *et al* (2005); Thanoon *et al* (2003)
CF_2	Manufacturing capability and product quality problems	Jaillon *et al*., 2009; Kamar *et al* (2009)
CF_3	Lack of skilled labour in IB	Swierk, 2005; Jaillon *et al*., 2009
CF_4	Limited site space for placing prefabricated building components	Tam *et al*., 2007
CF_5	Lack of supply chain	Chiang *et al*., 2006
CF_6	Higher initial cost	Swierk, 2005; Jaillon *et al*., 2009; Tam *et al*., 2007
CF_7	Lack of on-site cast yard area	Jaillon *et al*., 2009
CF_8	Lack of codes and standards	Kamar *et al* (2009); Hussein (2007); Warszawski (1999)
CF_9	Monotone considerations	Vikan, 2008
CF_{10}	Constructability issues	Nawi *et al* (2007); Thanoon *et al* (2003)
CF_{11}	Lack of resource, R&D and IB centres	Nawi *et al* (2011); Nawi *et al* (2005)
CF_{12}	Lack of assessment, certification, training and education	Hamid *et al* (2008); Hussein (2007); Thanoon *et al* (2003)
CF_{13}	Resistance from customers and professionals	Kamar *et al* (2009); Nawi *et al* (2011); Warszawski (1999)
CF_{14}	Lack of hoist equipment capacity	Jaillon *et al*., 2009
CF_{15}	Inflexibility of design	Swierk, 2005
CF_{16}	Legal and cultural issues	Kamar *et al* (2009)

Table 2 Demographic information of respondents

Variable	**Categories**	**Number of cases**	**Frequency (%)**
Gender	Male	72	80.9%
	Female	17	19.1%
	Missing	0	0.0%
Education	PhD and Master degree	36	40.4%
	Bachelor degree	41	46.1%
	Certificate or Associate degree	8	9.0%
	High School graduate	4	4.5%
	Missing	0	0.0%
Job position	Professor and Associate Professor	33	37.1%
	Researcher	9	10.1%
	Project manager	18	20.2%
	Consultants	8	9.0%
	Engineers	12	13.5%
	Other	7	7.9%
	Missing	2	2.2%
Working experience (engaged in IB)	<3	39	43.8%
	3-5	18	38.3%
	5-10	17	19.1%
	>10	13	14.6%
	Missing	2	2.2%

Table 3 Indicator scores

Indicator code	All (N=89)		Business practitioners (N=47)		University academics (N=42)	
	Mean	SD	Mean	SD	Mean	SD
CF_1	3.44	0.78	3.04	0.66	3.88	0.67
CF_2	3.56	0.80	3.13	0.65	4.05	0.66
CF_3	4.00	0.71	3.98	0.71	4.02	0.72
CF_4	2.91	0.76	2.81	0.71	3.02	0.81
CF_5	3.79	0.63	3.66	0.60	3.93	0.64
CF_6	4.18	0.68	4.15	0.69	4.21	0.68
CF_7	3.09	0.76	2.98	0.71	3.21	0.81
CF_8	3.79	0.76	3.49	0.62	4.12	0.77
CF_9	2.67	0.64	2.57	0.62	2.79	0.65
CF_{10}	2.78	0.70	2.70	0.72	2.86	0.68
CF_{11}	2.79	0.75	2.81	0.77	2.76	0.73
CF_{12}	2.85	0.75	2.77	0.70	2.95	0.79
CF_{13}	2.72	0.80	2.68	0.84	2.76	0.76
CF_{14}	2.90	0.83	2.79	0.93	3.02	0.68
CF_{15}	2.97	0.87	2.96	0.83	2.98	0.92
CF_{16}	2.99	0.70	2.98	0.77	3.00	0.62

Table 4: Degree of membership of factors for CFs

CFs	Business practitioners	University academics	Integrated value based on fuzzy set theory
	$\mu_{\tilde{A}_D}$	$\mu_{\tilde{A}_P}$	$\mu_{\tilde{A}}$
CF_1	0.526	0.906	0.906^*
CF_2	0.578	0.944	0.944^*
CF_3	0.917	0.924	0.961^*
CF_4	0.394	0.512	0.512
CF_5	0.864	0.927	0.943^*
CF_6	0.952	0.962	1.000^*
CF_7	0.488	0.604	0.605
CF_8	0.785	0.927	0.930^*
CF_9	0.245	0.370	0.370
CF_{10}	0.339	0.417	0.418
CF_{11}	0.402	0.371	0.408
CF_{12}	0.369	0.476	0.477
CF_{13}	0.351	0.377	0.384
CF_{14}	0.410	0.514	0.515
CF_{15}	0.480	0.490	0.507
CF_{16}	0.489	0.500	0.517

*Note: The degree of membership is more than 0.85.