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Factors impeding the offsite production of housing construction in China: an investigation of current practice

XIAOLIN ZHAI[1]*, RICHARD REED[1] and ANTHONY MILLS[2]

[1]*School of Management and Marketing, Deakin University, Melbourne, Australia*
[2]*School of Architecture and Building, Deakin University, Melbourne, Australia*

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The promotion of offsite production is a possible future strategic direction for the construction industry as it provides economic, environmental and social benefits. However, in China, the uptake of offsite production, particularly in the housing sector, is relatively low and few studies have identified and examined the reasons behind this trend. This research gap is addressed and factors that inhibit the wider use of offsite production in China's housing construction industry are investigated. A questionnaire survey was carried out, examining the views of 110 construction professionals in China including developers, designers, contractors, manufacturers and suppliers. Factor analysis of 21 separate variables was undertaken which extracted six principal factors, namely: 'constructability implementation', 'social climate and attitudes', 'architectural performance', 'costing', 'supply chain' and 'preparatory stage'. The findings identify both barriers and challenges to increasing the uptake of offsite production in China. This provides a rare insight about the housing construction industry in China with possible implications for other developing countries that are seeking to identify and overcome barriers to the wider uptake of offsite production.

Keywords: China, housing construction, offsite production, sustainability.

Introduction

The construction industry has historically acknowledged the direct and indirect benefits of undertaking offsite production, especially in terms of improved quality, productivity, efficiency and safety. Currently, with reference to a receptive climate regarding sustainability, offsite production has been identified as an effective method to deliver sustainable construction when compared to traditional construction approaches. In the UK the take-up of offsite production in construction has been consistently presented for its contribution to a higher level of sustainability (Department of Trade and Industry, 2001). The Australian government also identified the potential for the construction industry to benefit from offsite production and achieve best practice in the sustainable construction process by 2020 (Hampson and Brandon, 2004). With additional ongoing emphasis placed on increasing the level of sustainable construction, Taylor (2010a) argued there was a high possibility that the offsite production sector would outstrip traditional construction processes in the construction industry.

In the housing construction industry, offsite production has links to the evaluation of construction methods in most industrialized countries. For example the offsite manufactured housing industry in Japan produces approximately 150 000 outputs per annum where Linner and Bock (2012) acknowledged it is one of the strongest construction industries in the world. Their study found that offsite production processes also represent a considerable proportion of the housing market in many European countries such as Austria and Germany, with rises of 33% and 15% respectively being observed in recent times.

*Author for correspondence. E-mail: xzhai@deakin.edu.au

In comparison, housing construction in China has received widespread criticism for its negative performance with respect to relatively inferior quality, lower productivity levels, excessive use of resources, high energy consumption, large amounts of construction waste, high levels of environmental pollution, as well as poor labour force health and safety records. With substantial global pressure being placed on China's housing industry to increase the uptake of sustainable practices, offsite production has been repeatedly promoted as a potentially viable alternative in China (Ministry of Housing and Urban-Rural Development, 2011). However, despite these compelling arguments, the housing construction industry remains slow to react due to certain barriers.

The aim of this research is to identify and examine factors affecting the uptake of offsite production in China's housing construction processes. Though a limited number of earlier studies examined potential barriers to the wider use of offsite production in certain countries such as the UK (Blismas *et al.*, 2005), USA (Polat, 2008), Australia (Blismas and Wakefield, 2009) and European countries (Nadim and Goulding, 2011), no specific study has focused on the use of offsite technology in the rapidly developing construction industry in China where the tension between the large-scale residential developments and sustainability has increased substantially. To achieve the research objective, a wide range of stakeholders in China's housing construction industry have been surveyed in order to collect the primary data. The research findings provide an invaluable insight into the perception of and knowledge about offsite production processes in China. It is anticipated the findings from this study will encourage housing industry bodies and researchers in China and may be extended to an international context when seeking to accelerate offsite production in developing countries.

Demands for offsite production in China's housing construction industry

China currently is experiencing an enormous construction boom. In 2010, the construction industry provides an important foundation for the nation's economy, equating to a gross domestic product (GDP) of 6.5% and employing about 42 million people in 71 863 construction-related enterprises (National Bureau of Statistics of China, 2011). In particular housing construction has grown substantially since the late 1990s with a total investment of RMB 3051.27 billion in 2009, equating to an overall increase of more than 700% since 1998 (National Bureau of Statistics of China, 2011). With reference to aggregate built area, the total area of new residential buildings under construction in urban areas in 2010 exceeded 3.76 billion square metres (National Bureau of Statistics of China, 2011).

Even though the housing construction industry in China has experienced sustained high growth over the past two decades, a shortfall in housing supply remains a critical problem for China's construction industry. Today, in excess of 10 million urban households still live in poor quality dilapidated residential buildings which need to be gradually demolished and then replaced with higher quality accommodation (UN-Habitat *et al.*, 2010). However, the housing construction industry in China has been widely criticized for low levels of industrialization where the labour productivity levels have been estimated at less than one-fifth of the levels of developed countries (United Nations, 2004). The current intensive labour content in the housing construction industry in China presents many challenges at a time when the construction industry is urgently seeking improved efficiency and productivity coupled with higher quality.

Despite the pressure on increasing levels of productivity, there is also a need to promote environmentally friendly strategies to address sustainability concerns. Clearly the large increase of construction activities in China has presented many environmental issues with associated excessive use of limited natural resources, higher levels of energy consumption, additional waste production and increased pollution. The enormous amount of waste from construction and demolition activities has become a major contributor to severe ecological damage and environmental degradation in urban China (Wang *et al.*, 2010). The excessive depletion of natural resources in China is directly linked to four segments of the housing construction industry in China: water, land, construction materials and energy (Ji, 2011).

The challenges associated with the housing construction processes in China are not limited only to low productivity and poor environmental records; there are direct implications for social issues as well. Over the past two decades the rapid pace of labour-intensive housing construction in China has benefited from the high availability of cheap labour. Most housing construction workers in China are at low educational levels and have relocated from rural areas into urban cities without adequate professional training. Many of these unskilled workers are employed in the construction industry using informal employment agreements where few workers appear to understand how to claim their social rights. As a result many workers receive relatively low wages, although they experience an intensified workload and high-risk working conditions, often without guaranteed

insurance arrangements or compensation for workplace injury and/or illness (Ji, 2011).

The uptake of higher levels of industrialization in the housing construction industry has been supported from a political perspective in China. In 1998 China's Ministry of Housing and Urban-Rural Development established the Centre for Housing Industrialization (CHI) as a dedicated authority with the mandate of bolstering the transition from labour-intensive housing construction towards an increasing use of offsite production processes. The policy document titled *The Twelfth Five-year Plan* (*2011–2015*) *for China's Construction Industry* confirmed the necessity of the use of offsite production in the housing sector with the emphasis on meeting the demand for increased quantity and quality levels combined with addressing environmental considerations (Ministry of Housing and Urban-Rural Development, 2011).

However, the uptake of offsite production in the housing construction industry has arguably been very slow. Although the government appears to be trying to meet increasing housing demands which incorporate higher levels of sustainability, there are very few housing developers in China using offsite construction (Liu and Ying, 2009). It can be argued that only a few large multi-functional firms with the integrated capacity of housing investment, product research and development, design, component manufacturing, construction, sales and property management can actually provide a wider uptake of offsite practices (Zhang and Skitmore, 2012). The commonly adopted housing construction methods, particularly in relation to the construction of high-rise apartment buildings, are dominated by conventional labour-intensive approaches involving considerable onsite labour input.

Aside from the reluctance in practice, few studies have examined offsite production in China and in turn the knowledge about offsite methods remains very limited. There has been little attention given to examining the advantages and disadvantages of adopting offsite production in China (Zhang and Skitmore, 2012). Pan (2007) undertook a relatively small number of interviews and case studies to investigate the potential use of industrialized systems in high-rise housing construction in Chongqing, China. However the study was limited to economic characteristics, without undertaking a wider consideration of offsite construction practices. A later study (Arif and Egbu, 2010) concluded that the use of offsite production was potentially an effective approach to meet increasing demand for housing in China; however, the dataset was very limited and also lacked any accompanying in-depth analysis to adequately examine the practical issues of offsite construction in China. Earlier studies provided a sound basis for housing construction in China to move towards an increased implementation of offsite production; however, no study investigated industry perceptions affecting the final decisions about the option of using offsite production. It is therefore critical to identify and examine factors restricting the wider uptake of offsite production in China's housing construction industry.

Literature review

It can be seen from other industries, such as the manufacturing industry, that the key feature of offsite production is based on the relocation of most activities from onsite to an offsite factory-controlled environment. This relocation in turn can provide a variety of benefits to the overall building process when compared with the traditional site-based construction approach. Despite the acknowledged advantages, the acceptance of offsite construction processes still remains much lower than anticipated. An investigation into the use of offsite production by the top 100 house-builders in the UK found the overall level of support for offsite production to be low, with most respondents arguing against the increased use of offsite production methods in the housing market (Pan *et al.*, 2007). Notwithstanding that the UK plays a leading role in the global use of offsite production where the market value is estimated at approximately £6.5 billion (Taylor, 2010a), there is a strong argument that the use of offsite production in the construction industry still remains lower than it could be (Pan and Sidwell, 2011).

Initiatives encouraging the use of offsite production have been actively promoted by governments in most countries, especially in developed countries where the goals of sustainable construction are active. However the changes to a new construction model would be difficult without fully understanding the level of industry perception. Blismas *et al.* (2005) argued that the uptake of offsite production in the UK has been hindered by the construction industry's inability to fully understand and appreciate the inherent constraints of this approach. Pan *et al.* (2007) also confirmed problems existed and affected a wider uptake of offsite production in housing construction with regard to the lack of understanding about the incentives and barriers in the industry.

The main consideration associated with uptake of offsite production processes is usually the cost barrier. The decision criteria used to select the optimal construction approach are primarily cost-based rather than value-based (Blismas *et al.*, 2006). There is a general perception in housing construction that the

use of offsite production is comparatively more expensive than conventional construction methods (Birkbeck and Scoones, 2005). The economic issues in offsite production including the large initial capital outlay and hard-to-achieve economies of scale are perceived by industry practitioners as significant barriers (Pan and Sidwell, 2011).

Further, the previous studies have also placed an emphasis on the managerial perspective at different stages of offsite manipulation. Generally, the predominant partnerships or relationships within the housing construction industry today between clients, designers, developers, contractors, manufactures and suppliers are short term and segregated. The designers and property developers usually hold a view that the traditional construction methods can provide the higher possibility for the flexibility and variability of building design than use the large extent of standard prefabricated components (Venables *et al.*, 2004; Blismas *et al.*, 2005). From the perspective of the building contractors, major house-builders in the UK are relatively content with the use of traditional onsite construction methods in contrast to offsite production because of the established processes and procedures (Pan *et al.*, 2007). An additional inhibitor is the supplier capacity, which is sometimes associated with risks like 'loss of factory production slot/production capacity', 'suppliers failing to deliver on time' and 'manufacturer insolvency' (National Audit Office, 2005). In Australia for example it has been reported that there is severely limited supplier capacity of offsite products in Western Australia where the industry is small and relies on eastern regions but with very high transport costs (Blismas, 2007).

In addition to managerial and procurement barriers, several 'softer' factors in terms of cognitive issues have been observed which are particularly significant. It is evidenced that there are negative public perceptions associated with the post-war prefab-housing, which in turn strongly influenced the market demand for offsite housing by homebuyers (Edge *et al.*, 2002). There is a general public perception that houses built with offsite production methods or prefabricated systems are only used for public housing to cater for a low-income stratum. There is also an indication that the end user of housing products often shows relatively little interest in the actual housing construction processes (Pan *et al.*, 2007). Market resistance largely affects the incentives of offsite innovative methods in the housing construction industry. The lack of relevant guidelines, official policy, specific legislation and definite information in the marketplace is addressed as a knowledge barrier bias against the use of offsite in housing construction (Blismas and Wakefield, 2009).

From a global perspective, the share of housing output in China today is substantially increasing; however, the actual operation of the housing construction industry today incorporates a high level of consumption with relatively low records of efficiency. The scenario of low industrialization in the construction process substantially hinders efforts to deliver sustainable construction. Established knowledge in the literature has generally overlooked the uptake of offsite construction in the Chinese context. It is argued that the analysis of factors affecting the development of offsite production that are relevant to China may also encourage future studies into offsite construction innovation in other developing countries.

Research method

Research design

The purpose of this research was to identify industry perspectives about barriers to the uptake of offsite technology in China's housing construction sector and further ascertain the principal factors. According to Yin (2009) and Robson (2011), the questionnaire survey is the most common and best method for research on capturing the data about general behaviours, views and opinions with a strong positivistic flavour. A number of preceding studies have used the questionnaire survey as an effective means to collect the primary data of the industry perspectives on the use of offsite production. Therefore, the questionnaire survey was identified as the most appropriate research method for this study.

With the research design, the survey was carried out with a collaborative organization in Beijing which was able to provide a valid and accessible contact list of offsite businesses across China. This organization was a prominent industry body of offsite innovation in China which was formed in 1980. A total of 420 firms nominated by this organization were all the proactive industry bodies of offsite innovation in China who maintain long-term working partnerships with it. This list served as a representative population to which to distribute the survey.

The questionnaire consisted of three individual sections. Section one collected general information about each respondent including the professional qualifications, industry experience and specific characteristics about their respective industry organization. Section two examined their perception of the preferred construction methods currently used in the housing construction industry in China. Section three asked survey participants about 21 identified variables linked to barriers regarding the uptake of offsite production in China's urban housing construction

Table 1 List of identified or perceived barriers to the application of offsite production in construction industry

Code	Variables
D1	Higher capital costs
D2	Higher initial costs
D3	Longer capital payback period
D4	Longer lead-in time
D5	The inability to freeze the design early on
D6	Lack of enough flexibility
D7	Monotonous design with poor aesthetic criteria
D8	Lack of previous experience and guidance
D9	Higher skill demands for the labour
D10	Specific demands for the site logistics for pre-finished elements protection
D11	Highly restrictive construction tolerances
D12	Poor integration for the supply chain
D13	Increase in complexity for maintenance
D14	Transportation
D15	Manufacturing capacity
D16	The fragmented nature of the construction industry
D17	Poor quality impression
D18	Client scepticism and resistance
D19	Lack of available codes and standards
D20	Lack of governmental support
D21	Lack of confidence of the industry in offsite production

industry. The 21 variables were based on aspects of offsite construction derived from the existing literature (see Table 1). The survey participants were asked to rank each barrier by using a five-point Likert scale (1 = least, 5 = most). To overcome any potential bias associated with rigid closed questions, each respondent was given the chance to provide additional information about other perceived barriers of offsite production they considered were relevant.

As all survey participants were based in China and most had limited English language skills, the questionnaire was translated into Chinese. In order to achieve the semantic, conceptual and normative equivalence of the questionnaire, the forward-translation and back-translation approaches were adopted to ensure the questions were comprehensible and unambiguous.

Data collection

An initial pilot study was conducted with 15 construction practitioners via either e-mail or telephone. The invited participants were architects, engineers, housing contractors and component manufacturers which each had over 20 years' housing industry experience in China. Considering the absence of previous studies in China, the pilot study focused on examining and testing the design and format of the survey, the relevance of the allocated scales and content validity of the questionnaire.

From the list supplied by the collaborative organization, 298 experts and professionals were randomly selected for the survey. Their area of expertise related to a diverse range of housing construction-related disciplines including design/architecture, planning, construction, component manufacturing and suppliers. Collaboration with the industry body meant the survey participants were reliable and ensured a high degree of reliability and validity of the collected data. The use of the random sampling strategy also ensured that the survey was able to achieve a high level of generalizability (Creswell, 2003).

The respondents in the survey were required to access a web-based survey where an initial e-mail was sent advising the address of the URL (internet) webpage link. A later follow-up reminder e-mail was sent to the respondents who did not return the survey within two weeks after receiving the initial questionnaire. The website containing the survey could be accessed between December 2011 and February 2012.

Data analysis instruments

Before the detailed analysis was undertaken, the initial stage was to examine the reliability of the scaled responses to ensure consistent and stable results in the survey. The Cronbach's test as the most common check for internal consistency was used to test reliability. The value of Cronbach's coefficient alpha should fall between 0 and 1 where a higher value (i.e. closer to 1) indicates a great reliability. In this study the value of alpha was at least 0.7 which ensured the results were reliable before proceeding to the next stage of the analysis.

As the main objective of this research was to identify the factors associated with potential barriers that influence the adoption of offsite methods in housing construction, exploratory factor analysis was undertaken. The three main steps conducted in sequential order to ensure reliable results were: (1) evaluation of suitability of the data for factor analysis; (2) factor extraction and identification; (3) factor rotation to assist identification of high loading variables and interpretation (Pallant, 2011).

During the analysis, both Kaiser-Meyer-Olkin (KMO) and Bartlett's Test of Sphericity in SPSS were used as two statistical measures to confirm the

data were suitable for factor analysis. The computed values of KMO above 0.6 and p-values of Bartlett's Test less than 0.05 were confirmed as an acceptable range to undertake further analysis. Principal components analysis (PCA) is the commonly used method of factor analysis where only factors with an eigenvalue exceeding 1.0 were retained for further investigation. After the factors were extracted, Varimax method was used to rotate the factors and identify high loading variables to assist with interpretation and naming of each factor.

Characteristics of sample set

A total of 110 survey responses were collected eventually which represented an overall response rate of 37%. It is commonplace for construction practitioners in China to undertake multiple roles in the building process; therefore respondents could be associated with more than one profession in the survey. The majority of respondents indicated their professional roles were: architects (38%), engineers (27%), developers (26%), contractors (14%), manufacturers and suppliers (13%) and others (7%). The respondents were employed by different organizations which were geographically distributed throughout Chinese metropolises to reduce potential bias, rather than being restricted to only one geographical location. The respondents were employed in organizations including property development companies, design firms, contractor firms, consultant institutes and manufacturing enterprises with 63% of firms having more than 200 employees. With direct reference to individual survey participants, 18% of respondents had industry experience exceeding 20 years, 44% had between 11 and 20 years of experience and 38% less than 10 years of industry experience.

Discussion of findings

With reference to determining the appropriate sample size for the factor analysis, Costello and Osborne (2005) demonstrated that the previously standard rule regarding the requirement for a 'large or small' sample size for factor analysis was practically eliminated when relying on the subject-to-variables ratio. With this approach the actual number of observations should be at least five times the number of variables (Floyd and Widaman, 1995; Fabrigar *et al.*, 1999; Hair *et al.*, 2006). In this analysis the 110 responses obtained from the survey exceeded the ratio to the 21 variables in Table 1 and therefore the data were deemed suitable for the next stage of data analysis.

The Cronbach's coefficient alpha for the internal consistency test was the important criterion to ensure the reliability of the scales prior to undertaking the data manipulation. The results confirmed the internal consistency of the 21 variables (D1–D21) was acceptable with Cronbach's coefficient alpha value 0.835 which exceeded the minimal requirement of 0.7.

Prior to undertaking extraction of the factors, it was assessed to what extent the data from 110 valid responses to variables (D1–D21) were suitable for the factor analysis. The result from the Kaiser-Meyer-Olkin (KMO) test was 0.731 which exceeded the minimum acceptable value of 0.6. In addition the p-value of Bartlett's Test of Sphericity was 0.000 which confirmed an acceptable level of statistical significance. Therefore the results indicated the data supplied by the respondents were appropriate for the factor analysis in the next stage.

The PCA initially extracted six constructs with eigenvalues greater than 1.0. The factor loadings on individual variables within each construct were then examined and the derived factor evaluated. With this approach the higher loadings on individual variables ensure such variables are more representative with regard to their individual contribution to the overall factor (Hair, 2006). It has been shown that for a sample size between 5 and 10 participants per variable, the item loadings should exceed at least 0.4 (Floyd and Widaman, 1995). Hair (2006) further argued the significant factor loadings based on a sample size between 100 and 120 responses were 0.55 and 0.5 respectively. Working within these guidelines, factors with low loadings (e.g. variable D8 with a factor loading of 0.434) were removed for recomputing the remaining significant variables.

Finally, a factor analysis was undertaken of the remaining 20 variables (D1–D7, D9–D21) and produced six underlying factors which were clearly identified after undertaking rotation (see Table 2). The six factors with eigenvalues of 4.87, 2.54, 1.97, 1.54, 1.24, and 1.14 collectively explained 66.53% of variance with clear, strong factor loadings greater than 0.5. For the purpose of assisting interpretation the six constructs were assigned names as follows: *constructability implementation* (factor 1), *social climate and attitudes* (factor 2), *architectural performance* (factor 3), *costing* (factor 4), *supply chain* (factor 5), and *preparatory stage* (factor 6).

Factor 1: Constructability implementation

The first factor was named 'constructability implementation', being associated with restrictive construction tolerances, specific demand for the site logistics

Table 2 Rotated factor matrix of barriers to the uptake of offsite production in China's urban housing construction industry

	Latent factors						
Reduced set of 20 variables	Factor 1 Constructability implementation	Factor2 Social climate and attitudes	Factor 3 Architectural performance	Factor 4 Costing	Factor 5 Supply chain	Factor 6 Preparatory stage	Communality
D11. Highly restrictive construction tolerances	0.878	–	–	–	–	–	0.789
D10. Specific demands for the site logistics for pre-finished elements protection	0.795	–	–	–	–	–	0.758
D9. Higher skill demands for the labour	0.692	–	–	–	–	–	0.532
D12. Poor integration for the supply chain	0.513	–	–	–	–	–	0.491
D20. Lack of governmental support	–	0.808	–	–	–	–	0.685
D19. Lack of available codes and standards	–	0.764	–	–	–	–	0.639
D18. Client scepticism and resistance	–	0.759	–	–	–	–	0.641
D21. Lack of confidence of the industry in offsite production	–	0.605	–	–	–	–	0.506
D7. Monotonous design with poor aesthetic criteria	–	–	0.814	–	–	–	0.739
D6. Lack of enough flexibility	–	–	0.745	–	–	–	0.799
D13. Increase in complexity for maintenance	–	–	0.574	–	–	–	0.563
D17. Poor quality impression	–	–	0.505	–	–	–	0.572
D2. Higher initial costs	–	–	–	0.876	–	–	0.803
D1. Higher capital costs	–	–	–	0.775	–	–	0.664
D3. Longer capital payback period	–	–	–	0.630	–	–	0.655
D14. Transportation	–	–	–	–	0.800	–	0.746
D16. The fragmented nature of the construction industry	–	–	–	–	0.767	–	0.756
D15. Manufacturing capacity	–	–	–	–	0.728		0.702
D5. The inability to freeze the design early on	–	–	–	–	–	0.793	0.729
D4. Longer lead-in time	–	–	–	–	–	0.671	0.536
Eigenvalues	4.868	2.543	1.972	1.539	1.240	1.143	–
Percentage of variance	24.34	12.713	9.860	7.697	6.201	5.717	–
Cumulative percentage of variance	24.340	37.053	46.913	54.610	60.811	66.528	–

for pre-finished elements protection, skill demands for the labour and poor integration within the supply chain. The concept of 'constructability' has generally been understood as a means of achieving optimum integration of construction knowledge and experience in planning, engineering, procurement and field operations in the building process to balance the various project and environmental constraints to achieve overall project objects (Construction Industry Institute, 1986). When compared to traditional onsite construction processes, offsite production involves undertaking most operations in advance, which requires incorporating all key stakeholders as part of detailed planning.

Therefore, it is no surprise that constructability implementation remains a major challenge for Chinese practitioners when seeking to increase the uptake of offsite production. A successful implementation of constructability would be strongly influenced by the entire project team with an integrated goal. To plan and implement an offsite construction process must involve a high level of communication, coordination and integration between developers, designers, contractors, builders, manufacturers and suppliers. However, the current status of the housing construction industry in China can be described as a diverse range of fragmented trades which are extremely difficult to coordinate due to the absence of a clearly defined project management plan prior to commencement of a construction project.

The ineffective construction issues are also related to traditional building procurement. Normally the housing construction process in China is based on the 'design-bid-build' approach where usually excludes the contractor and other supporting stakeholders at the front-end stage of a project. However without closer interaction of the contractor and manufacturer at the commencement of project, the design and planning phases in the offsite construction approach cannot achieve the required high level of practicalities. Furthermore the lack of competence and experience relating to the offsite production approach also contributes to a substantial barrier to knowledge about the constructability implementation on projects.

Factor 2: Social climate and attitudes

Factor 2 was assigned the name 'social climate and attitudes', which included lack of governmental support, lack of available codes and standards, client scepticism and resistance, and lack of confidence of the industry about offsite production. An observed difference from factor 1 was the reference to the internal contradictions in the construction industry, where factor 2 referred to the public and social climate directly linked to the external environment.

In comparison to construction industries in Western countries, the government in China undertakes a decisive role in economic and social development with substantial influence. Therefore if innovative approaches to construction result in a higher use of offsite production, arguably this will not be possible without government intervention. In recent decades the Chinese government has consistently highlighted the economic contribution from the housing construction sector; however, adequate attention has not been given to incorporating technological developments and innovation. There are no clear policies in existence to support the promotion of offsite production in housing construction. Furthermore many industry practitioners, particularly private housing developers, appear to have a general lack of interest in construction innovation, especially when it relates to the construction method. Offsite production is generally perceived as a complex technology which challenges aspects of traditional construction culture.

Public policy and regulation instruments in China regarding the use of offsite production methods are also considered inadequate and immature. Overall government regulatory policies and procurement exert a strong degree of influence on demand and therefore play an important role in promoting change via the uptake of new construction technology (Gann and Salter, 2000). However, in China there are relatively few progressive laws, regulations, codes and standards specifically addressing offsite production methods. This lack of enforcement of regulations and measures highlights the difficulties faced by stakeholders seeking to adopt effective offsite practices.

Without adequate promotion and incentives provided by the Chinese government it appears the public perception of construction methods including offsite production remains defensive. In urban areas the general public has limited knowledge and little education about modern housing which is constructed off site. They often regard the industrialized construction process as associated with 'more cost and less choice' than the traditional onsite labour-intensive construction approach. The application of offsite production processes has not been generally perceived as an opportunity to address the issue of a housing shortfall and the challenges of sustainability.

Factor 3: Architectural performance

Factor 3 relates to the 'architectural performance' of offsite production which includes attributes of monotonous design, limited flexibility, complexity for

maintenance and a poor quality impression. This factor placed an emphasis on the building's physical characteristics including architectural aesthetics, flexibility and functionality for potential offsite production.

In general a standardized, modularized and repetitive design is the important and underlying foundation when looking to implement offsite construction methods at the early stage of the project. However it has previously been argued that the excessive repetitiveness and standardization of processes involved with offsite production acted to prevent its wider application in the housing construction industry (Warszawski, 1999). It has been demonstrated that variations in architectural design are less frequent when offsite and prefabrication processes are adopted (Jaillon and Poon, 2010).

Following the completion of housing reform[1] in 1998 in China, there has been a substantial improvement in the quality of high-rise condominiums in urban regions. Despite challenges associated with external factors, the availability of flexible residential layouts and a high level of diversity are deemed as the major advantages in the competitive residential real estate market. However, many respondents indicated that the design versatility and aesthetics would actually suffer from using offsite production methods. A large number of developers believed projects initiated in offsite production posed very high risks of cost and time uncertainties when modifications are needed during construction.

In reference to architectural considerations linked to offsite production, it has been shown that developers and designers in China did not fully understand the advantages associated with offsite production. Architects and engineers generally cannot gain adequate support in terms of both time and financial inputs from the developers who are otherwise reluctant to innovate. Many designers have stated that it was very hard to obtain a thorough consideration of using offsite construction methods at the design stage because of the pressure of deadlines and budget.

Factor 4: Costing

Factor 4 was related to 'costing' of offsite production with reference to higher initial costs, higher capital costs and a longer capital payback period. The economic parameters are usually a very important component of the decision-making process when selecting the optimal construction method.

The main economic benefits of offsite production are generally associated with labour and material savings, rapid erections of structures, lower maintenance and repair expenses (Polat, 2008; Jaillon and Poon, 2010). Findings from previous studies have confirmed that the level of awareness about overall project cost savings due to offsite implementation has substantially increased over time (Goodier and Gibb, 2007; Polat, 2008). Nevertheless, the financial performance of offsite production remains a controversial issue. From the construction industry's perspective, the perception of higher capital cost and initial outlay has previously been argued as a substantial barrier to improving offsite production over the long term (Pan *et al*., 2007, 2008; Blismas and Wakefield, 2009). Undertaking a direct comparison of the cost of high-rise building construction, the construction costs associated with offsite production are about 20% higher than those of the conventional onsite construction process (Jaillon and Poon, 2008).

The challenges associated with costing in the Chinese housing industry may be more complex than first envisaged. The enormous manufacturing capacity and comparatively low cost of labour in China have been identified as attractive features in terms of providing a boost to offsite production in China's housing construction industry (Arif and Egbu, 2010); however in reality the outcome appears to differ. The offsite production process is not well suited to the construction of one-off buildings (Taylor, 2010b). The benefits gained from economics of scale by using offsite production are difficult to fully evaluate unless there are regular and continuous bulk orders. The cost efficiencies gained from the moulds, equipment and facilities for specific offsite production systems or elements are largely dependent on the desired final output. However the typical residential development model in China, characterized as including independent reconfiguration, somewhat unpredictable future output capacity and varying construction site locations in the current housing construction industry, cannot ensure long-term demand for the volume of product units. Therefore this eliminates obvious cost benefits gained from economics of scale.

Another concern related to expensive costings is linked to the way of comparison. Most stakeholders in the housing construction industry often compare the offsite methods with the conventional onsite approaches over the short-term timeframe. The concept of the cost effectiveness of offsite production has not received much attention from a whole-of-life costing perspective when evaluating the optimal construction method to adopt. Furthermore there is also a disparity between China and Western countries regarding the economic benefits derived from reduced labour costs, primarily due to the availability of cheap labour in China. Housing construction in China predominantly has relied on the use of low cost massive

labour as the main competitive advantage for the past decades. Offsite production as a high industrialization construction method has been criticized for its additional requirements of education and training to employees, especially for some small and medium-sized enterprises.

Factor 5: Supply chain

Factor 5 was identified as 'supply chain' as it included variables relating to transportation, the fragmented nature of the construction industry and also the manufacturing capacity. The supply chain is a term used to describe a network of organizations that are involved in, predominantly through upstream and downstream linkages, different processes and activities which add value in the form of products and services for the benefit of the client or ultimate customer (Christopher, 1998). Transferring activities from the site to the supply chain has been identified as a high priority and is a practical initiative to advance the construction process (Vrijhoef and Koskela, 2000).

Supply chain practices cannot improve individual efficiencies in isolation as they are directly reliant on efficient integration at three levels: cooperation, coordination and collaboration (Briscoe *et al.*, 2004). When directly compared to the onsite construction approach, it is clear that offsite production is substantially more sensitive to variations in supply chain integration. The concept of integration must apply at all stages and also within and between organizations involved in the offsite construction process, rather than simply being based on segmented collaborative working relationships. In China integration and coordination in the construction delivery system are arguably very poor, including the relationships between stakeholders such as between designers/architects and contractors, between contractors and manufacturers, and also between homebuyers and developers. Additional challenges are also due to the relatively few alliances between organizations involved in construction procurement. A large number of parties involved in the construction execution normally working individually with its own target but very low level of mutually shared information and communication flowing directly attributed to the lag in offsite uptakes in housing development.

Transportation is a logistical yet critical problem directly affecting the offsite production supply chain in China. Because of the challenges associated with the substantial initial capital outlay required to ensure offsite economics of scale, many housing contractors, component manufacturers and suppliers need to overcome challenges with uncertain site locations, complex distribution processes and logistical difficulties. With the increasing complexity levels of construction projects, the housing construction process in China must urgently improve the level of supply chain integration from a managerial perspective.

Factor 6: Preparatory stage

Factor 6 was labelled 'preparatory stage' and focused on the initial stage of offsite construction with specific reference to the inability to freeze the design early on and the length of lead-in time. Previous studies have also identified the long lead-in time as a substantial barrier to the wider uptake of offsite construction (Venables *et al.*, 2004; Goodier and Gibb, 2005; Pan *et al.*, 2007).

Clearly, successful offsite construction activities are directly dependent on sound preparation and detailed planning at the preparatory stage of the project. The distinctive nature of offsite production processes in construction requires an extended preparatory period in order to accurately define the architectural design, confirm availability of labour and offsite components, and coordinate timelines between different parties, transportation accessibility, technological solutions and other associated factors. However, the majority of Chinese residential developers engaged in the housing industry today generally do not have enough patience to set a longer period for the preparatory phase; the reasoning is linked to concerns about excessive timing and capital cost. On the other hand, urban residential development underway in China is usually characterized by frequent changes in the market which also affect other variables including design, materials, workforces and facilities. Incorporating advanced fixed scheduling would likely be considered as a risky approach by the construction industry in China.

Conclusion

Promoting the use of offsite production in housing construction has been officially acknowledged as a key tool for encouraging efficient, effective and ecologically sound practices in the housing construction industry in China. However the same construction industry in China has provided negligible support, if any, for the offsite proposal. There has been an obvious lack of studies investigating industry perceptions about the limited use of offsite housing construction processes in China and the associated reasons. In this study there were 110 questionnaire survey responses completed by experienced construction industry stake-

holders in China which identified a smaller number of principal factors affecting the wider use of offsite technologies in housing construction. A total of six factors were generated from 21 proposed variables by factor analysis: 'constructability implementation', 'social climate and attitudes', 'architectural performance', 'costing', 'supply chain' and 'preparatory stage'.

None of the six identified individual factors can be viewed in isolation as they collectively contribute to an enhanced understanding about the barriers to the uptake of offsite construction in China. The first two major factors relating to 'constructability implementation' and 'social climate and attitudes' indicated that the softer issues arising from the housing construction industry were substantially more significant than the 'hard' issue linked to the third factor, being the physical 'architectural performance'. It was noted the 'costing' factor was identified as the largest significant barrier in previous studies; however the survey respondents disagreed and indicated this factor was not a major barrier in the Chinese scenario. The final two factors, namely 'supply chain' and 'preparatory stage', were also identified in previous studies and confirmed here as significant barriers which prevented China's urban housing construction industry from undertaking a higher level of implementation of offsite production.

The findings provide clearly identified barriers and challenges linked to the wider uptake of offsite production in China's housing construction industry, especially when considering the unique circumstances which differ from developed countries. Because of the inherent differences between China and Western countries in terms of the social, economic, and institutional features, it is essential to strongly encourage government, industry practitioners and researchers in China to cooperate in seeking a common goal and employ strategies to encourage higher innovation in offsite housing construction over the short, medium and long term. It was also acknowledged that positive intervention of government and regulatory agencies is essential in China. The large-scale government sponsored affordable housing projects in most urban regions may present an ideal opportunity for the housing construction industry to achieve a higher uptake of offsite technological innovation. This can involve establishing and disseminating contemporary knowledge, improving the procurement process and providing reliable data and feedback in order to educate the traditional 'wait-and-see' residential market. To enhance the uptake of offsite production, industry practitioners should conduct a thorough comparison between traditional construction methods and offsite production in terms of the quality levels, productivity levels and contributions to environment and social developments.

Although these findings are specific to China, it is envisaged that certain aspects are transferable to other developing countries experiencing severe housing shortages with associated low existing levels of industrialization. Further research is encouraged and should involve qualitative and mixed method studies into offsite production supported by interviews or focus groups to validate the research findings. The case study of specific projects would also be encouraged to provide an in-depth analysis when the detailed, reliable and valid data can be obtained.

Note

1. For a very long time urban housing in China was fully developed, distributed and managed by the government or state-owned enterprises as 'welfare' for the households who lived and worked in cities. The Chinese government launched the housing system reform in 1988 with the policy to allow the land to be transacted in the marketplace and to allow private residential real estate development. The urban subsidized welfare housing system was eventually abolished in 1998 and the majority of the housing projects in urban regions are developed and transacted as commodities in the market.

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