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INCREASING THE LEVEL OF SUSTAINABILITY VIA OFF-SITE PRODUCTION

A study of the residential construction sector in China

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ABSTRACT

Even though the use of off-site production in the construction process for residential buildings is seen as a viable means of increasing the level of sustainability with respects to its significant economic, environmental and social contributions, there have been very few studies to-date into off-site construction within the context of developing countries where the places have crucial demands for accommodations. Accordingly this research involves the rapidly growing developing nation, China, as a representative developing country with the objective to investigate the current status of off-site practices in the urban residential construction sector. This paper also examines the factors affecting demand for and potential barriers against a wider uptake of off-site technologies in China. The findings provide a rare insight into off-site construction in China's housing industry and this information will be transferable to other developing countries. This study also contributes to a broader understanding about the off-site construction in developing from an international perspective.

Keywords: off-site production, sustainability, housing construction, China, developing country.

1. INTRODUCTION

The call for sustainable development in the built environment has been significant increased throughout the world, and the 'sustainability' is commonly accepted as the critical role of the construction industry in the 21st Century. To promote the building and construction into a sustainable way has been addressed as the most potential to contribute the world to achieve the sustainable development (Bakens, 2003) . Twenty years ago, Kibert (1994) initially presented the term of 'sustainable construction' as the creation and responsible maintenance of a healthy built environment, based on ecological principles, and by means of an efficient use of resources. Although nowadays there are some arguments regarding the difficulty to define sustainable construction since the constantly increased issues occur to the knowledge, the sustainable construction as an universal conception has a general agreement on the acknowledged features would not be restricted to the ecological aspect, but also economic, social and societal aspects from a long-term view (United Nations, 2010).

Off-site production in construction with the distinctive nature to transit most of the on-site works and operations into a controlled manufacturing environment makes the high possibility for the sustainable construction. Many authorities in developed countries have committed to promote the sustainable construction with high involvement of off-site production though were proposed in different terms. For instance, the UK Department of Trade and Industry (DTI, 2001) emphasised the sustainability agenda of prefabrication in building process, and identified the great capacity of off-site manufacturing to overcome the challenges of sustainability in construction industry. In Australia, off-site manufacture has been concluded as the one out of nine key themes for the Australian construction industry to achieve the leading sustainable practice (Hampson and Brandon, 2004). Similarly, the Building and Construction Authority in Singapore (BCA, 2011) also declared that the extensive prefabrication in the building construction is the important way to deliver the sustainable, easy and safe-to–build practices in Singapore.

Despite the importance of off-site production for the construction industry has been widely studied in the context of developed world, however, it is argued that the increased use of off-site production probably have more substantial value to help the construction industry in major developing countries with large populations and rapid development to coping with sustainable development, for example, China. Although the theoretical framework of off-site in developed countries could have significant meaning regarding to guide the conceptual framework in developing countries, the barriers and challenges of the use of off-site production in developing ones are argued as substantially different. Responding to this situation, this research engaged China, a typical developing country as a case in order to examine the current scope and uptake of the off-site production in China's residential construction industry, 2) investigate the industry perceptions regarding the driving forces and barriers associated with increased use of off-site production in China and furthermore, and (3) identify the likely future for the uptake of off-site construction.

2. URBAN RESIDENTIAL CONSTRUCTION IN CHINA

The construction industry currently is quite active in Chinese economy which contributed over 6.6% of GDP and employed nearly 42 million people through 71,863 construction enterprises (NBSC, 2011).In particular, the investment of residential construction in urban areas was achieved 3402.6 billion RMB in 2010, and the aggregated floor area for newly built housing during the China's Eleventh Five-Year Plan1 period (2006-2010) had exceeded 3.79 billion square metres (NBSC, 2011). There is the estimation of another 30 billion square metres of the building floor space will be achieved by 2020, and the residential construction in urban regions will be the high-volume contributor (MOHURD, 2007).

China is known as the world's most populous country where the total population achieved 1.34 billion by 2010 approximately (United Nations, 2011). Driven by the rapid urbanisation in China, there was 621.86 million people in total lived in cities and town up until 2009 (UN-HABITAT et al., 2010). Given the very high demands for the accommodations in urban China, the conflicts between the conventional housing construction pattern and the tendency for sustainable development are growing in recent years. The external pressures associate with a sustainable construction perspective have been argued throughout the society such as: the rapidly expanding urban residents, significantly decreasing urban land and natural resources, worsening urban environment, the growing demands of high building quality and durability, efficient use of resource, energy and water as well as a healthy and safe working environment for the workforce etc.

In fact, the residential construction in China traditionally relies on the intensive labour works as the competitive advantage. Although nowadays most of the building components are mechanised in factory environment, the general integration of industralisation in the residential construciton is at the relatively low degree. The widely held perspective on the housing construction in China is as a wasteful and dangerous industry in comparision to the Western with characters of lower productivity, high energy, resources and materials consumptions, large amounts of construction wastes, high levels of environmental pollution, shorter building life cycle and very poor worker health and safety records. At the same time, it is also worthwile to note that the particular marketing pattern for most newly-constructed residential buildings sold in Chinese cities and towns. For many years that the new flats in China's property market are sold without any fitting-out which force the households to rebuild and reconstruct the internal housing individually before moving in. This scenario in turn directly creates a series of more extreme issues in terms of unsustainable

[1] China's *Five-year plan is* the national economic development guideline for the central government of People's Republic of China (PRC) to establish and map the entire country's economic development strategies with respect to set the economy growth targets and launch reforms for every five years. After the First Five-year plan (1953-1957) launched in1953, China now is at the stage of the Twelfth Five-year (2011-2015) phase.

individual construction behaviours without sufficient and systematic sustainability guidance. Just take the construction waste as one indicator, it has been estimated that to fit out a new 90 square metre apartment by independent household would averagely produce 2 tonnes of additional construction-related garage without appropriate post-treatments in urban places(China Daily, 2010).

In 1998 the Chinese government established the Centre for Housing Industrialisation (CFHI) as a dedicated authority with the specific assignment to promote the transition of the labour-intensive residential construction industry towards an increased off-site construction process. The newly policy titled 'the Twelfth Five-year Plan (2011-2015) for China's construction industry' also identified the high potential for use of off-site production in the housing sector with the aims of meeting both the increasing quantity and quality housing demands in urban China combined with addressing environmental considerations (Ministry of Housing and Urban-Rural Development, 2011). Also, there are various local favourable policies and schemes in terms of the encouragement of initiatives of off-site in the residential construction process have been proposed in sequence. However, there is little information available and poor database in China regarding the current practices of off-site in the housing construction, which consequently increases the uncertainty of improving the off-site production.

3. PREVIOUS STUDIES ON OFF-SITE PRODUCTION IN CONSTRUCTION INDUSTRY

3.1 The significant relationships between off-site production and sustainable construction

Off-site production in construction is usually refers to divide and relocate the major building construction process independently into a controlled industrialised environment prior to the final assembly on the construction site. Based on the integration of pre-manufactured techniques and technologies from low to high, Gibb and Isack (2003) categorised the off-site production into four levels with reference to (1) component manufacture and sub-assembly, (2) non-volumetric pre-assembly, (3) volumetric pre-assembly and (4) modular building. Compared with the traditional on-site construction activities, the distinctive nature of off-site production makes the high possibility for the construction industry to improve the performance of sustainability with respect to the significant economic, environmental and social benefits.

Economic significances

A shorter construction duration, higher productivity and controlled mechanised quality are generally acknowledged as the primary economic advantages of off-site production in the construction industry (Gann, 1996, Venables et al., 2004, NAO, 2005, Pan et al., 2008, Gibb and Isack, 2003). Although the significance of cost reduction has been last argued as the controversial attribute of off-site production, Pan and Sidwell (2011) proved that off-site construction for apartment buildings can effectively reduce the capital cost and did not result in a higher construction cost than conventional options when combined with an effective management. In fact, the considerations of the economic benefits of off-site production should be an all-inclusive and the whole-life cost concept rather than a direct and immediate cost saving; this is also linked to enhanced cost certainty, reduced maintenance costs, lower overall lifecycle costs, minimised site overheads and additional economic benefits from early occupations (Blismas et al., 2006, Buildoffsite, 2010).

Environmental significances

The unique feature of off-site production enables much of the building elements and process to be prefabricated in the specialised factory can significantly evaluate the eco-efficiency step when compare to the traditional construction behaviours. The environmental significances of off-site production have been widely studied. Tam et al. (2007) concluded that off-site production in the high-rise building construction can effectively reduce the material wastage, particularly in four major material tasks being plastering, concrete, rebar and tiling which can be significantly reduced by 100%, 92%, 90% and 74% respectively. Also, increasing the possibilities of recycling and reusing building components and materials, improving the energy and water consumption efficiency, reducing the air pollution,

diminishing noise, dust and community disruption have collectively acknowledged as the extensively environmental benefits of off-site production (Jaillon, 2009, Taylor, 2010, Gorgolewski, 2008).

Social significances

The conventional labour-intensive construction has a poor reputation in the world wide with respects to the inferior working environment. Statistics from the International Labour Organisation (ILO, 2008) demonstrated that the injury and accident rate of Australia construction industry is about 10 times higher than for the equivalent industry in Japan where the prefabrication level is leading in the world . The process of off-site production can improve an arguably safer and stable working condition to most of the workforce which can significantly reduce the accidents and occupational illness. In the developing countries, the increased uptake of off-site production can also make more labours involved in the training processes and became semi-skilled and skilled workers who can achieve higher earning capacity than traditional labours.

3.2 The impediments of wider uptake of off-site production

In the previous studies, researchers have well documented the impediments of off-site production in order to help achieve a faster and extensive take-up within the construction industry in certain developed economies such as Europe, the UK, the USA, Australia and etc. (Polat, 2008, Nadim and Goulding, 2011, Arditi et al., 2000, Goodier and Gibb, 2005, Blismas and Wakefield, 2009).The identified impediments in this paper were clearly arranged into two broader themes namely the 'soft' and 'hard' constraints.

The 'soft' constraints

The 'soft' constraints here are generally referring to the awareness issues that violate the public expectations of off-site production. The primary barrier that frequently cited in the literatures is the expensive cost of off-site production. Undoubtedly, economic performance is the most important issue when industry consider the adaptation of construction alternatives (Warszawski, 1999). Albeit the reputed uptake of off-site production in the developed country, the UK, Blismas et al. (2006) found that the evaluation system currently used to select the optimal construction approach is still solely relied on a direct cost-based rather than value-based system. The housing developers generally are speculative and the primary concern is generally with the finance management, rather than the actual construction process (Venables et al., 2004). However, the increased capital cost and higher initial cost have long been criticised as the most significant factors that impede a wider take-up of off-site production (Nadim and Goulding, 2010, Goodier and Gibb, 2005, Venables et al., 2004, Pan et al., 2008). Pan (2011) recently argued that perception of higher construction costs of offsite deeply embedded in mentality and practices of the industry and even professional advisers.

At the same time, the market resistance is regarded the other important 'soft' obstacle to the off-site production application, particularly in the residential sector. In the European countries, the UK and Japan, the sharp growing of off-site production for the prefabricated housing was initiated after the Second World War as the most effective solution to sever housing demands. However, the traditional images of off-site constructed housings are socially given as the symbol of inferior and poor public housing by considerable Western publics (Goodier and Gibb, 2007, Warszawski, 1999, Blismas and Wakefield, 2009).The established market attitudes towards the off-site constructed housing unfortunately remains the other important soft barrier. Nadim and Goulding (2011) also addressed that there is a trend to build goes to individualisation and the market demands for the off-site production are not high as it was expected.

The 'hard' constraints

Technology innovations in any areas have to face a series of knowledge-based hardship and the construction industry cannot be the exception. The off-site building construction works are more complex when compared with labour-intensive methods since the particular machinery process and operation require integral knowledge and well coordination between developers, designers, contractors and off-site manufacturer and suppliers. However, from the perspective of the designer and the developer, the inflexible design and rigid to change substantially influence the

initiatives to use off-site production(Venables et al., 2004). The long-lead in time and the lack of skilled worker are the argued as the significant barriers from the contractor perspective (Goodier and Gibb, 2005). Also, compare to the diverse and abundant choices of 'individual' building components today, the fairly small scope of the off-site production supply chain has to been emphasized(Blismas and Wakefield, 2009). Venables *et al.* (2004,P31) depicted the dilemma context of the off-site supply chain that:

……Off-site manufacturers are willing to ensure their systems are applicable to established designs from developer, finalising the design earlier for most off-site manufactures systems than for traditional construction methods. Off-site manufactures to standardise components and minimise variations on the production line that sit awkwardly with the desire of developers or planner. Also, the design lead-in time for off-site production may not readily fit in with the existing construction and procurement schedules of contractors…….The tension as well as between the off-site manufactured components and site produced work considerable variation in the tolerances expected by manufactures and builders.

Based on the reviewing of pervious research on off-site production, it has been found that the majority of studies were under the scenario of the developed world and the development and practices of off-site production in developing countries were overlooked. Within this context, this study therefore seeks to demystify the current situations of the use of off-site technologies in the developing countries based on the extensive survey with the residential construction industry in China. Specifically, three research questions in this research are addressed as follows:

1) What is the uptake of off-site construction in China's urban residential construction industry?
2) What are the typical driving forces for the residential construction industry in China to embrace the off-site construction?
3) What are the potential barriers with reference to the wider uptake of off-site production in China?

4. METHODOLOGY

Given that the aim of this study was to explore general perception and the extent to which the off-site production adopted in China's residential construction industry, a questionnaire survey was conducted to collect the primary data required for the analysis. The questionnaire consisted of three sections: (1) general background information about each participant; (2) their current preferred residential construction method and their use of off-site production, and (3) perceptions of driving forces and barriers with the implementation of off-site production. In the section (3) as shown in Table 1, these 21 driving forces and barriers respectively were based on the accepted knowledge about off-site construction derived from the existing literature and also including integrated opinions from experts in China. The survey participants were invited to respond to each question by using a 5-point Likert scale (1= least, 5= most). To overcome the bias of rigid closed questions, each respondent was given the chance to add information about other perceived barriers of off-site production which they considered were relevant but might not listed in the survey.

Table 1 List of the driving forces and potential barriers towards the wider use of off-site production in China's urban residential construction

Driving forces	Potential barriers
B1. Achieve high building quality	D1. Higher capital costs
B2. Decrease construction time	D2. Higher initial costs
B3. Ensure construction time certainty	D3. Longer possession period for the capital
B4. Ensure the project cost certainty	D4. Longer lead-in time
B5. Reduce the labour demands and cost	D5. The inability to freeze the design early on
B6. Reduce the building whole life cost	D6. Lack of enough flexibility
B7. Improve the project constructability	D7. Monotonous design with poor aesthetic criteria
B8. Increase property marketing value	D8. Lack of previous experience and guidance
B9. Increase the speed of return on investment	D9. Higher skill demands for the labour
B10. Reduce on-site workers health and safety risks	D10.Higher demands for the site specific and logistics for pre-finished elements protection
B11. Well controlled design and construction	D11. Highly restrictive construction tolerances
B12. Reduce the households individual reconstruction behaviour to damage the building	D12. Poor integration for the supply chain
B13. Reduce the on-site dust, noisy pollution and local community disruptions	D13. Increase the complexity for maintenance
B14. Reduce the energy consumption in construction	D14. Transportation
B15. Reduce the material waste	D15. Manufacturing capacity
B16. Reduce the construction waste	D16. The fragmented nature of the industry's structure
B17. Improve the reusable and recycle building elements	D17. Poor quality impression
B18. Promote the green building technologies uptakes	D18. Client scepticism and resistance
B19. Increased customisation options	D19. Lack of available codes and standards
B20. Improve the competitive capacity	D20. Lack of the governmental supports
B21. Take more governmental policy supports	D21. Lack of confidence of the prefab industry

A pilot study was conducted within a small group of industry professionals in China through emails and online discussions, prior to finalise the formal questionnaire. Then, the final 298 online questionnaires together research invitation letters were administrated by email to identified practitioners in China's housing industry. The invited

participants were intended to cover a wide range of professions which included developers, architects, engineers, contractors, manufacturers and suppliers. The survey was consistent from the December 2011 to February 2012 for three months in total. In order to achieve larger sample size, the "Snowball" sampling approach was also employed where participants were to ask to help distribute the survey link to more suitably qualified industry professionals who were considered as suit to this survey.

As presented in the Table 2, there were 110 responses validated for the survey which contributed to a 37% respondent rate. Given that most construction practitioners in Chinese built environment normally have multiple qualifications, therefore some respondents were indicated more than one profession in the survey responses which were also regarded as valid. In this survey, the majority of participants were architects (38%), engineers (27%), developers (26%), contractors (14%), manufacturers and suppliers (13%) and others (7%). The respondents were came from a wide spread of organisations with property development enterprises, design institutes, contractor companies, consultant institutes and manufacturing enterprises with 63% of firms had more than 200 employees. Within the respondents, over 42% had high experience in industry more than 15 years, 21% had 11-15 years of experience and 37% with less than 10 years.

Table 2 Classifications of the survey responses

Respondents	Number of responses	Percentage (%)
Architects	42	38%
Engineers	30	27%
Developer	28	26%
Contractors	15	14%
Manufacturers and suppliers	14	13%
Others	8	7%

(Note: In China the construction practitioners often have multiple qualifications across the building process; therefore some respondents were indicated more than one profession in the survey responses which were also regarded as valid).

5. RESEARCH FINDINGS

The construction methods for the residential buildings

Respondents were asked to indicate the frequency of construction methods for high-rise apartments according to their experience, where a reply of 1 was 'never' and 5 was 'very often'. The findings revealed that the onsite casting system significantly posed the leading building approach for the apartment projects with a highest mean value (4.07), which was followed by steel-concrete structure (3.43), on-site casting frame with precast slabs (2.81), full steel frameworks (2.75) and precast panel units (2.57).

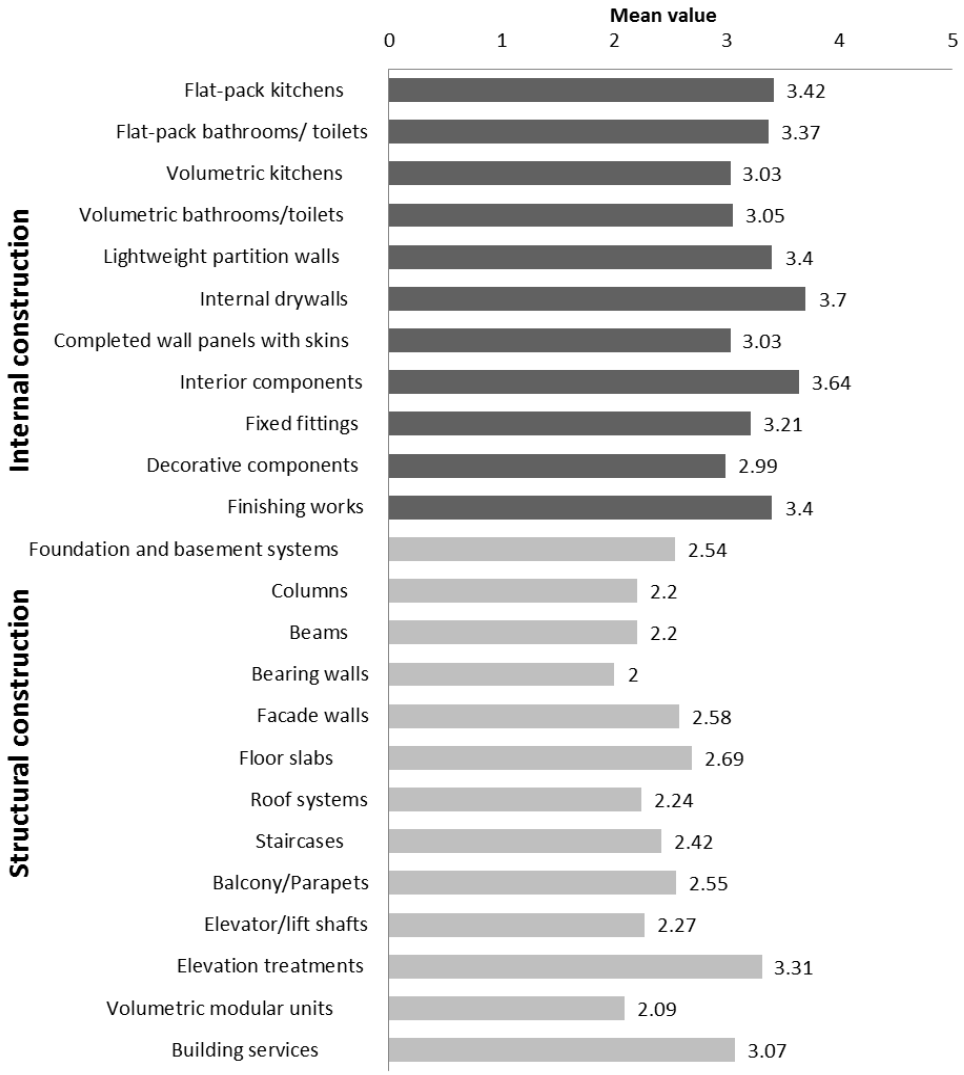
It is not surprise to see that the onsite casting as the most acceptable construction method for the apartment construction in China. The site cast concrete is commonly perceived by industry and the wider society in China as the most economic and effective method that can achieve the desired physical building performance. For the past two decades of the speed-up urbanisation process in China, this may true due to the abundance of cheap and regular labour supply to the overwhelming residential construction. The urban housing construction in China has long-term relied on the cheap

labour and material costs as the competitive advantages. Therefore, compared to the higher technical and management requirements on off-site construction, the conventional labour intensive pattern with most of construction actions on site were consequently more preferable in current Chinese context.

The level and extent of off-site production in urban housing construction

The investigation into the uptake of off-site production was designed into two divisions, namely the building internal construction and structural construction thereof. Generally, the survey demonstrated that the uptake of off-site production for the housing internal finishing use was slightly higher than the applications in structure, however, the overall level was very low (Figure1). The use of drywalls was the most prevalent off-site application with the highest mean value of 3.7. Also, major interior components and finishing works (mean value of 3.64 and 3.40 respectively) featured with fairly simple technical requirements such as doors, windows, pelmets, elbowboards and interior staircases, were mainly achieved the prefabrication. However, for the high-rise structural building process, the results revealed that there is very limited extent of off-site applications, particular for the load bearing frameworks, for examples, columns (2.2), beams (2.2), and bearing walls (2).

Figure 1 The applications of off-site production in China's urban housing construction



1='Never', 2= 'Rarely', 3='Sometimes', 4= 'Often' and 5= 'Quite often

Although the general extent of off-site production is argued as poor, it is good to find the increased use of using off-site production and prefabrication for the housing internal and finishing construction. This trend can substantially change the public perception of a 'new' housing rather than the 'empty box' traditionally. The fitted-out units may positively guide and help the urban residents towards a more sustainable living and performance model unlike the situations we discussed in the section two.

Driving forces of using off-site production in China

Respondents were asked to rate the significance of 21 identified driving forces that can influence the decision making of off-site production by using a five-point Likert scale where 1 was 'very ineffective' and 5 was 'very effective'. Summarising the responses from the survey, the ranking of importance were presented in Table 3 based on the mean values. Within the results, the first important factors were found as (1) reduce construction waste (3.99), (2) decrease construction time (3.99), (3) reduce the on-site dust, noise/pollution and local community disruptions (3.94), (4) reduce the material waste ensure (3.85), (5) construction time certainty (3.76), (6) reduce the labour demands and cost (3.70), (7) improve the project constructability (3.70), (8) reduce energy consumption in construction (3.67), (9) promote uptake of green building technology (3.65) and (10) ensure the project cost certainty (3.56).

Table 3 Ranking of driving forces to improve off-site production in housing construction

Description	Total Frequency	Mean	Std. Deviation	Rank
B16. Reduce construction waste	110	3.99	0.91	1
B2. Decrease construction time	110	3.99	0.85	2
B13. Reduce the on-site dust, noise pollution and local community disruptions	110	3.94	0.87	3
B15. Reduce the material waste	110	3.85	0.87	4
B3. Ensure construction time certainty	110	3.76	0.80	5
B5. Reduce the labour demands and cost	110	3.70	0.88	6
B7. Improve the project constructability	110	3.70	0.83	7
B14. Reduce energy consumption in construction	110	3.67	0.94	8
B18. Promote uptake of green building technology	110	3.65	0.97	9
B4. Ensure the project cost certainty	110	3.56	0.90	10
B10. Reduce on-site workers health and safety risks	110	3.50	0.94	11
B12. Reduce the households individual reconstruction behaviour to damage the building	110	3.50	1.08	12
B6. Reduce the building whole life cost	110	3.49	0.93	13
B1. Achieve high building quality	110	3.42	1.01	14
B21. Take more governmental policy supports	110	3.38	1.00	15
B17. Improve the reusable and recycle building elements	110	3.33	1.03	16
B11. Well controlled design and construction	110	3.32	0.96	17
B9. Increase the speed of return on investment	110	3.29	0.93	18
B20. Improve the competitive capacity	110	3.04	1.00	19
B19. Increased customisation options	110	2.76	1.01	20
B8. Increase property marketing value	110	2.71	0.98	21

(1= very ineffective, 2= ineffective, 3= neutral, 4=effective, 5= very effective)

It can be observed that items related to environmental considerations were posed the major proportion among the top ten factors. Five out of the first ten factors were related to the environment such as 'B16 reduce the construction waste', 'B13 reduce the on-site dust, noisy pollution and local community disruptions' ,'B15 reduce the material waste', 'B14 reduce the energy consumption in construction' and'B18 promote the green building technologies uptakes'.

At the same time, the familiar advantage of off-site production regarding the time priority also confirmed in this study, see the 'B2 decrease construction time' and 'B3 ensure construction time certainty', were respectively being the second and fifth key drivers. However, the most frequently cited key benefit of off-site production, the improved quality, did not get the high mark as what it was in the previous studies. To 'achieve high building quality' by using the off-site production was suspected by the industry which might explain the reason why the off-site application rarely used in mainly structural construction process for the high-rise apartment building.

Impediments of using off-site production in China

Respondents were also asked to rate their agreements of 21potential barriers that can affect the selection of off-site production by using a five-point Likert scale where 1 was 'strongly disagree' and 5 was 'strongly agree'. Table 4 showed the descending order that can be found that the biggest obstacle to the use of off-site production is the 'D19. lack of available codes and standards' with the mean value of 4.03. The scarcity of relevant legislations and accreditations for the varieties of off-site production in China is a broader societal problem which increases the difficulty to application of off-site.

Then, the 'technical constraints' were also mainly considered as the significant barriers within the first ten identified barriers which included 'D12. poor integration for the supply chain'(mean value of 3.95), D11.highly restrictive construction tolerances (3.94), D5 the inability to freeze the design early on (3.91), D10.higher demand for the site specific and associated logistics for pre-finished element protection (3.88), D9. higher skill demands for labour component (3.83) and D8. lack of previous experience and guidance (3.74). The increasing complexity of off-site high-rise building process and a lack of sufficient technological professionals and skilled workers in China, leave a growing suspicion of off-site practices in the residential construction.

Table 4 Ranking of impediments of using off-site production in housing construction

Description	Total Frequency	Mean	Std. Deviation	Rank
D19. Lack of available codes and standards	110	4.03	.87	1
D12. Poor integration for the supply chain	110	3.95	.79	2
D11. Highly restrictive construction tolerances	110	3.94	.87	3
D20. Lack of the governmental support	110	3.94	.85	4
D 5. The inability to freeze the design early on	110	3.91	.83	5
D10. Higher demand for the site specific and associated logistics for pre-finished element protection	110	3.88	.82	6
D18. Client scepticism and resistance	110	3.88	.75	7
D9. Higher skill demands for labour component	110	3.83	.87	8
D21. Lack of confidence in the prefab industry	110	3.82	.89	9
D8. Lack of previous experience and guidance	110	3.74	.94	10
D4. Longer lead-in time	110	3.65	.86	11
D15. Manufacturing capacity	110	3.62	.85	12

D16.The fragmented nature of the industry's structure	110	3.59	.77	13
D1. Higher capital costs	110	3.55	.88	14
D17. Poor quality impression	110	3.51	.96	15
D2. Higher initial costs	110	3.46	.80	16
D6. Lack of enough flexibility	110	3.45	.85	17
D7. Monotonous design with poor aesthetic criteria	110	3.45	.88	18
D14.Transportation	110	3.41	.85	19
D13.Increase the complexity for maintenance	110	3.12	.89	20
D3. Longer possession period for the capital	110	3.07	.92	21

(1= strongly disagree, 2= disagree, 3= neither disagree or agree, 4=agree, 5= strongly agree)

It is also interesting to observe that 'high cost' and 'long lead-in time' which are most frequently noted in the previous studies as the two biggest barriers (Pan et al., 2005, Blismas and Wakefield, 2009, Goodier and Gibb, 2005), however were arguably less significant in current Chinese scenario.

6. CONCLUSIONS

The off-site production has been increasingly accepted as the effective modern construction alternative for a sustainable built environment globally given the wide range of benefits. However, the knowledge is generally related to the construction industry in developed countries with very limited information and data of the off-site practices in the developing world. In fact, the off-site production in developing countries is still under construction but has particular important role for struggling with sustainability. This study took China's residential construction industry as a case in order to have a closer look of the use of off-site production in the rapid developing country.

The fact is that the main drivers for utilising the off-site production in China were largely associated with environmental considerations that were illustrated by the survey. The boosting economic development in China and other developing countries may in similarity brings unprecedented opportunities to these countries while also associates highly implicit costs for environment regarding energy, resources and environmental deterioration. The developing countries now were generally facing more extreme issues with respect to embrace a well-balanced development model in order to contribute to a sustainable future. The growing awareness of environmental benefits can be presented as a very positive theme to encourage the construction industry and society in developing country to begin the shift of construction modes and further upgrade the application of off-site production.

The survey also found that the technical and expertise constraints were the primary barrier in China's housing construction industry rather than the cost barrier confirmed in the literature. This may be caused by the different research contexts since the living models are largely different between China and most Western countries. The apartment buildings with 20s or 30s storeys currently are the common accommodation in the metropolises in China but the constructability of the off-site production for the high-rise construction procedures are seen to be limited. Also, the traditional prefab apartment buildings constructed in 1960s' China with largely use of the precast concrete panels were historically criticised by the poor aesthetic and a series of functional defects nowadays.

Although the survey suggested that the uptakes of off-site production are very low compared to the developed countries with more than 63.7% respondents were not satisfied the current level, there is an increasing claim that an efficient and sustainable future for construction industry by using the off-site production, particularly for the urban housing sector. The shift appears to have begun. 79% of the respondents in the survey indicated the confidence of the wider use of off-site production in residential construction industry within the coming decade.

The research provides a valuable reference for the national and international industry bodies and researchers to better understand the future potential for the uptake of off-site production in China which may be transferable to other developing countries. The off-site production is a common theme for the construction industry in all countries under the pressure of sustainability, but it is important for the construction industry in developing countries to acquaint the good knowledge of off-site production and encourage the ones to find an appropriate and best-fit model enables corresponding to their particular situations. The research suggests that further investigation of off-site production in developing countries have to adopt a more holistic perspective.

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