A SYNERGISTIC SUPPLY CHAIN ENHANCING OFFSITE MANUFACTURING UPTAKE IN AUSTRALIAN HOUSE BUILDING

Sherif Mostafa[1], Nicholas Chileshe and Jian Zuo

School of Natural and Built Environment, Barbara Hardy Institute, University of South Australia, City East Campus, G.P.O. Box 2471 Adelaide, South Australia 5001, Australia

Offsite manufacturing could become a key innovation for the future of Australian house building due to its capacity in meeting the growing housing demand, green construction and fewer requirements for labour force. It is a modern construction method where house building involves offsite factories and onsite construction. Three major challenges for managing the two working sites are broken junction, jumbled on-site process and vague demands from unclear customers. The two sites have several forms of non-value added activities. On the other hand, the house customisation adds more complexities to the design specification that leads to slow response to achieve house customer demand in short time. This is a proposition paper which aims to explore the opportunity of offsite manufacturing in Australia. This research conducts the offsite manufacturing exploration by reviewing the related literature. The research discovers that incorporating lean and agile concepts could overcome the existing barriers of offsite manufacturing uptake in Australia. Therefore, four house building strategies: built to stock, assemble to order, design to order, and self-building house are introduced for different house building alternatives in Australia.

Keywords: Australian housing, offsite manufacturing, synergistic supply chain.

INTRODUCTION

In Australia, the residential building sector contributes significantly to the national economy with the overall production value reported as AUD 47 billion in 2010-2011. The sector involves many independent building organisations to construct separate houses and other residential buildings including semi-detached houses, townhouses, flats, units and apartments. Nevertheless, the values of work commenced in residential building are likely to be less responsive to the growth of other construction activities (ABS 2013). This situation may be resulted from housing supply and demand influences. The housing supply has been found not keeping in pace with the housing demand (NHSC 2013). A promising solution to successful increasing in housing supply is the offsite manufacturing (OSM) (Blismas and Wakefield 2009). It is a non-traditional construction method which involves two working sites: offsite factory and onsite construction. To generate effective delivery of OSM, the paper suggests the synergistic supply chain of lean and agile manufacturing concepts. These concepts with promising gains have been suggested to be transferred to house building production (Blismas and Wakefield 2009; Manley *et al*. 2009). Recognising the

[1] Sherif.mostafa@mymail.unisa.edu.au

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shortage of the Australian house building supply, the research is undertaken to understand the situation of OSM in Australia. Moreover, the study aims to integrate the knowledge on of lean and agile applications in the Australian house building context.

LITERATURE REVIEW

The Australian housing supply has been found in a shortage to serve the housing demand. This situation could be influenced by housing supply and demand factors. The Previous studies have discussed the Australian housing supply shortage from the housing demand side rather than the supply challenges (Liu and London 2011). This paper, therefore, includes discussion on the Australian housing shortage from the supply perspective. The paper presents a possible relationship between the house delivery and the construction method used. OSM is a suggested modern method that has capacity to increase the supply of housing in Australia (Manley *et al*. 2009).

While there is plethora of studies on OSM in Australia, some studies such as Blismas and Wakefield (2009) covered the drivers and barriers of OSM in the Australian built environment. The main drivers for OSM were the shortage of skilled labours, environmental sustainability advantages, reducing the occupational health and safety (OHS) risks, and improving value, productivity and quality. The main barriers were including low level of industrial knowledge on OSM, longer lead times and freezing the design in early stages. Blismas and Wakefield (2009) and Manley *et al*. (2009) revealed that opportunities of OSM uptake are centred on detached housing, high-density multi residential complexes, and public facilities. However, these previous studies did not suggest any strategy or framework that can be practically utilised to overcome the OSM barriers. This research, therefore, will explore further to what could potentially be the solutions for more effective OSM supply.

RESEARCH METHODOLOGY

This paper is presented as a proposition paper in which the the research aim is to explore the opportunity to the uptake of OSM in the Australian house building. The uptake of OSM in Australia can be subject to certain barriers that prevent house builders to pursue OSM. This notion will be included in this research investigation. To achieve the research aim, the methodology is designed into three phases to systematically collect and analyse the related materials.

Phase 1: A review of related OSM literature was conducted. At this stage, the opened online databases were explored. The databases include Emerald, Elsevier, Taylor and Francis, American Society of Civil Engineers (ASCE), CIB World, book publications, and Google Scholar. In addition, some published reports from Australian government and housing industry alliances were searched. This includes Housing Industry Association (HIA), National Housing Supply Council (NHSC), Australian Housing and Urban Research institute (AHURI), and Australian Bureau of Statistics (ABS). Data collection from the databases focused on the initiatives employed to explain the housing supply shortage, OSM uptake, and lean and agile in Australian built environment.

Phase 2: Explore the factors contribute to OSM uptake in Australia.

Phase 3: Develop an appropriate OSM supply chain model that could enhance the OSM uptake in Australia. The model development relied on the data analysis from the previous phases.

RESEARCH FINDINGS AND DISCUSSION

The opened online search discovered 169 accessible publications from 1992 to 2014 that met the data selection criteria specified at the first phase of the research methodology. These publications included 146 articles and 23 reports that reflected the OSM, house building shortage, and supply chain concepts including lean and agile practiced in Australia. Most of these publications focused on identifying the drivers and barriers of OSM. The evidence urging the use of lean and agile concepts and their combination was to overcome OSM barriers in Australia (Blismas and Wakefield 2009; Manley *et al*. 2009). The research findings are discussed as follows:

Factors influencing Australian housing supply

Australian housing sector has experienced housing supply shortage. The situation is evident through several studies on housing affordability (NHSC 2013) and housing completion time (Gharaie *et al*. 2010). Several factors have been mentioned as being contributed to the housing supply and demand. The Demographia Survey in 2014 highlighted the deterioration of housing affordability across 39 housing markets in Australia. The decline is likely caused by housing supply factors. The housing supply in Australia includes several stages such as strategic planning and development, land release, building approval, construction commencement and completion, and strata title registration and available for occupation (NHSC 2013). This paper focuses on the house construction process which starts from house building commencement and finished with house completion. As the latest statistics of ABS (2014a) indicated that the number of houses completed is lower than the number of houses commenced. The factors affecting the house supply are discussed as following.

Completion time for new houses
The house completion time is the time period between the first and last physical building activities to make house ready for occupation (Dalton *et al*. 2011). The house completion time is a major factor indicating the quality of housing delivery to house buyers. There is an increase in the average Australian house completion time, while the production rate has found to be relatively stable. The statistics of ABS (2014) reported the average completion times of new houses in Australian states, territories, and national level. Using 2003 to 2008 as a base line, the states of New South Wales, Victoria, South Australia, Tasmania, and the Northern Territory experienced increasing house completion time in 2008 to 2013. The house completion time remained the same in the states of Queensland and Western Australia, and Australian Capital Territory. The completion time progressively expanded in all regions in 2003 to 2008. The states of Western Australia and Victoria were recorded with the highest house completion time at approximately 3.3 quarters in 2013.

House buyers' design preferences
The house type and design are main factors of house buyer's preferences (NHSC 2013). The house preferences may vary from person to person based on some factors including household age and income, family size, and cultural background. The house preferences include the size, internal and external design, and location of the house. The average floor area of the Australian dwellings has been increased. The average floor area of new detached houses increased from 162.4 m2 to 248.0 m2 from 1984 to 2009 (ABS 2012). It is evident from an examination of volume builders catalogues such as of Metricon, one of the largest 20 home builders in Australia (HIA 2013), that double-story houses and more complex street facing façades has increased.

Level of skilled labour
The house building is labour intensive industry with its main product of new dwellings or renovated dwellings. The supply of labour is an important element of the housing supply. According to DEEWR (2012), there are shortages in some construction trades such as roof tiler, glazier, plumbers and cabinetmaker from 2008 to 2012. The house builders are working in a competitive environment that requires a skilled labour. The challenges include new working relationships such as partnering and virtual enterprise. The challenges are also include changing the construction technologies and adopting modern methods of construction. It can be concluded that the skilled labour is an essential component of the house building industry to achieve all the mentioned challenges. The skills shortages contribute to the undersupply of housing (NHSC 2013). As the construction work will be delayed due to the skilled shortage that requires some contracts with additional stakeholders.

House price
House prices is a critical element determining the new housing construction. In Australia, house prices have increased in all locations at similar rate of growth. The ABS (2014b) estimates that the Houses Price Index (HPI) for the weighted average of the eight capital cities increased by 3.4 % during December quarter 2013. It leads to an increase in the average HPI of the eight capital cities by 9.3% during the financial year 2012-2013. The housing supply is a function of house price. The house price includes land price, construction costs, and lagged house stock. The growth of house prices is driven by the increase in the prices of establishing houses. The study of Liu and London (2011) stated that the construction costs are responsible for a higher proportion of the increase in house prices in some regions. They concluded that the construction costs are a significant component of the poor performance of the Australian new housing supply.

Offsite manufacturing in Australia

In order to respond to the housing shortage, builders are looking for more efficient materials and new methods of construction. One example of new material is using Cross-Laminated Timber (CLT) in preference to traditional clay bricks. A new method is such as employing Offsite Manufacturing (OSM) with Structural Insulated Panels (SIPs) (NHSC 2013). OSM refers to the fabrication of house components in an offsite factory as well as their subsequent activities on a construction site (Goulding *et al*. 2012). It provides several benefits including improving onsite safety by providing cleaner and tidier construction site as well as enhancing quality of the house components under factory production. Moreover, OSM reduces environmental effects by reducing waste generation, shortening lead time and increasing the efficiency and productivity (Pan and Goodier 2012). The products produced using OSM fall into four categories (a) component manufacture and sub-assembly which always made in a factory and never considered for onsite construction (e.g. door, trusses, windows); (b) non-volumetric pre-assembly (panels) that are pre-assembled units which do not enclose usable space (e.g. wooden panels and Structural Insulated Panels (SIPs)); (c) volumetric pre-assembly (pods) which are pre-assembled units which enclose usable space and are typically fully factory finished internally, but do not form the buildings structure (e.g. bathroom and kitchen pods); and (d) modular systems which are pre-assembled volumetric units which also form the actual structure and fabric.

Previous studies positively addressed OSM in the Australian built environment. Hampson and Brandon (2004) suggested OSM as a key vision for improving the construction industry. Two research projects carried out by Blismas and Wakefield (2009) and Manley *et al*. (2009) confirmed that OSM has capability to produce high-volume and high-quality houses based on the efficiencies of the manufacturing principles. In spite of the benefits of the OSM, the factory production has several forms of non-value added activities including waiting time, transportation, defective products, and unnecessary motion (Womack and Jones 2003). Moreover, three major challenges arise from the management of two working sites concurrently. These challenges are the potential for lack of coordination between the offsite and onsite activities, the jumbled onsite processes due to difference between the production flow at offsite factories and construction flow onsite, and the vague demands from undecided customers (Chang and Lee 2004). These challenges might leads to slower response to achieve customer order. Some attempts have addressed the challenges of OSM by adopting successful concepts from the manufacturing industry, particularly lean and agile concepts (Höök and Stehn 2008; Vidalakis *et al*. 2013).

Application of lean and agile in OSM

Lean concept comprises of management practices that focus on eliminating all forms of wastes from the value stream (Sertyesilisik 2014). The concept has been widely adopted beyond its origin in the automobile manufacturing. Kenley (2014) emphasised on improving the productivity of construction industry through production systems intervention. Lean production concept is the best known intervention. It has been used by the house manufacturers in Japan by transferring the knowledge from automobile manufacturing to house manufacturing (Gann 1996). The practice of lean concept in house building requires using factory based production. However, the construction has unique characteristics (i.e. features of output, nature of processes, customer involvement, and supply chain). Therefore, lean construction has extended by Koskela (1992) to address the specific characteristics. The main challenge of lean construction is related to the interfaces between the OSM and the construction site. The production flow at the offsite factory is continuous and different from the construction site which is turbulent. This is due to uncertainties at the construction site such as changes in customer demand or site conditions. This leads to unpredictable delays to achieve the customer order. Agile construction was proposed by Daneshgari (2010) to proactively respond to any onsite uncertainties. Lean construction focuses on creating an efficient physical process of manufacturing. Agile, on the other hand, emphasises on high level of service through flexibility and customisation (Naim and Barlow 2003). These factors are important for OSM as OSM implies standardisation of products and processes, and emphasises on flexibility for house customers.

Some concerns were found from the existing literature in applying lean or agile as a standalone concept when uncertainties in construction are present (Christopher and Towill). Many studies suggested a combination of lean and agile concepts in OSM (Blismas and Wakefield 2009). However, these studies were conducted in different context to Australian house building environment. It was discovered further that no specific lean and agile integration strategy for OSM in Australia was formulated. Combining lean and agile within the whole supply chain can be accomplished by using the decoupling point and known as leagile (Purvis *et al*. 2014). In general, the decoupling point separates the supply chain into lean in the factory site and agile in the construction site.

SYNERGISTIC SUPPLY CHAIN FOR OSM HOUSE BUILDING

Christopher and Towill (2000) emphasise that supply chains must be in touch with market demand changes. The supply chain comprises all stakeholders involved to achieve customer order. The OSM house building supply chain suggested in this paper can be visualised as shown in Figure 1. The supply chain includes the house materials suppliers, offsite factory, designers, construction site, and customers. The Last Planner™ System (LPS) is used to establish a better coordination among supply chain stakeholders to achieve the house customer demand. LPS is used to transfer planning responsibility between construction organisation management and the field persons. The LPS facilitates the workflow so that labour and material resources can be more productive.

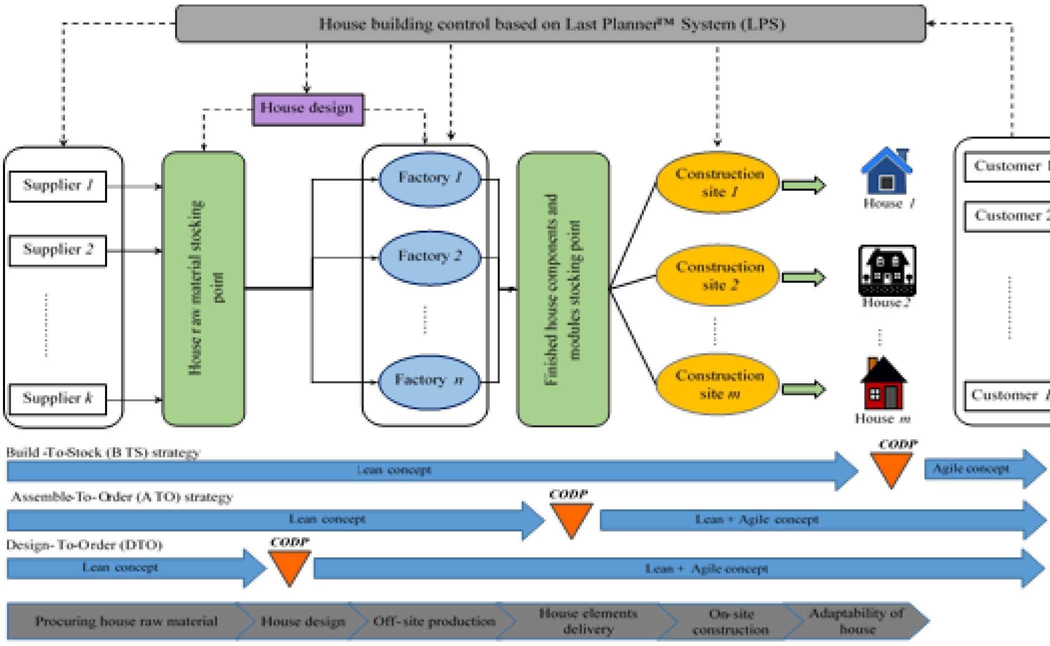

Figure 1: Synergistic OSM house building supply chain and included leagile strategies.

The LPS encompassing four levels of planning processes with different consecutive spans: master scheduling, phase scheduling, Look-ahead Planning (LAP), and Weekly Work Planning (WWP) (Forbes and Ahmed 2011).The master schedule defines the work to be carried out over the entire duration of a project. It identifies major milestone dates and incorporates critical path method logic to determine overall project duration. Phase scheduling generates a detailed schedule covering each project phase such as foundations, structural frame, and finishing. The phase employs reverse phase scheduling and identifies handoffs between the different specialty organisations to find the best way to meet milestones stated in the master schedule. LAP indicates the first step of production planning with a time frame ranging from two to six weeks. At this phase, activities are broken down into the level of processes, constraints are identified, responsibilities are assigned, and assignments are made ready (Hamzeh *et al*. 2012). WWP represents the most detailed plan in the LPS showing interdependence between the works of various specialist organisations. WWP guides the production process. At the end of each plan period, assignments are reviewed to measure the reliability of planning and the production system. Analysing reasons for plan failures and acting on these reasons is used as the basis of learning and continuous improvement.

OSM supply chain strategies

For competition, Christopher and Towill (2000) emphasise that supply chains must be in touch with market demand changes which can be divided into three critical dimensions; variety, variability, and volume. The supply chains may be lean prior to decoupling point and agile beyond decoupling point. The previous research of Childerhouse *et al*. (2000) and Naim *et al*. (1999) proposed a leagile model to be applied in the UK house building. The model was based on using material DP. In this paper, the leagile supply chain for Australian house building employs the customer order decoupling point (CODP) which suggested by Olhager (2003). The CODP in this study represents information and material DP. The material DP represents the stocking point of finished house modules or components. The information DP denotes the point where the customer order enters the housing supply chain. In this paper, four alternative positions for CODP, developing four house building strategies, are suggested to be employed in Australian house building supply chain. These strategies are discussed below.

Build-To-Stock (BTS) strategy

In BTS, the CODP located after the onsite construction activities and finished house building. This strategy is also known as speculative house. The houses are designed and built based on the builders' catalogue (Dalton *et al*. 2011). Customers have a choice to select from the available houses based on the location, cost, size, and design. The market winner in this strategy is the lower finished house selling price. Therefore, the activities before selling should be lean to fit the costs. While, agile is suitable after the CODP to diminish the delivery time. As a result, it maximize the customer satisfaction and the speed of return on investment.

Assemble-To-Order (ATO) strategy

The CODP is positioned at the offsite factory. The customers' houses are built according to the builder's catalogues. A variety of houses designs are included in the catalogues. Customers have a degree of flexibility to select a mix of 'specs' to match their demands. The customers can add extra features to their own kitchen, bathrooms, external living area, as well as upgrade standard items such as windows and doors (Dalton *et al*. 2011). The house builder then do the construction activities onsite and assemble the selected modules to complete the houses. The market winners in this strategy are the price and designs of house modules, and the completion time. It is suggested in this strategy to employ lean within the offsite factories. Agile will be employed in stages of shipments and onsite construction to ensure more responsiveness in delivering the houses.

Design-To-Order (DTO) strategy

In this strategy, the customer demand enters the supply chain at the design stage. Therefore, customers have a relatively high degree of customisation. They can specify the design of their own house modules. They have the flexibility to change on the predesigned modules to fit their needs. The market winner in this strategy is high customisation. Therefore, the house building stages need a combination of lean and agile. Lean is suitable for supplying the material and running the offsite factories, whilst the other activities need to be more agile.

Self-Build Homes (SBH) strategy

In this strategy, homeowner is significantly involved with the actual building process. The Australian housing is produced by small to large organisations. In 2012, the largest 100 builders commenced about 36% of all residential dwellings (HIA 2013). This proportion indicated that 64% of all residential have been constructed by small builders or in the form of self-building houses. The customers need to hire an architect for house designing, and builders and trades people for some onsite construction activities. Therefore, the key role of house building organisations is to supply the house components to the suppliers. House building organisations should make the house designs as simple as possible and provide variety of designs to meet different types of house needs. Lean is suitable to run the house modules factory, while agile is the best option for quick responses to demands of house components suppliers.

LINKING OSM STRATEGIES AND HOUSING FACTORS

This paper contended that the four housing supply factors mentioned earlier influence the shortage situation of the Australian housing. Moreover, these factors impacts the selection of the OSM strategies. The research findings confirmed the concept adopted from Fisher (1997) on matching the supply chain strategy to supply factors. The four OSM strategies suggested are not applicable to all housing supply factors. Table 2 demonstrates the association between the strategies and housing supply factors. Selecting the appropriate strategy depends on the house customer demand and the capacity of the house builder.

Table 2: Association of OSM strategies and housing supply factors

	BTS	ATO	DTO	SBH
Completion time for new houses	Short	Medium	High	Short–Medium
House buyers' design preferences	Low	Moderate	Very high	High
Level of skilled labour	Medium	Medium–high	Medium–high	Less labour
House price	Moderate rang	Moderate–high	High	Low–moderate

The house customer demand for a ready-to-move-in house makes BTS the suitable strategy. However, if the house customer own the land, the strategies are limited to ATO, DTO, or SBH. In the case of ATO and DTO, the customer and builder need to discuss the degree of house customisation in relation with completion time and price. Moderate degree of customisation in ATO results in medium completion time and moderate to high house price. On the other hand, the DTO allows the customer with more degreed of customisation with high completion time and price. The SBH strategy is appropriate for the customers whom are attempting to build their own homes. The strategy allows for savings in construction costs and completion time as well as more design preferences.

CONCLUSION

The Australian house building sector has experienced continuous housing demand. The house customer preferences, completion time and house price add more complexities to the design specification. OSM has been introduced as a solution to improve the housing supply in Australia. The OSM concept is originated from the manufacturing sector. To enhance OSM implementation, lean and agile manufacturing concepts as a synergistic supply chain can be integrated within the OSM supply chain. This synergistic supply chain offers four house building strategies: BTS, ATO, DTO and SBH. The four strategies attempt to answer different situations of house customer demand and capacity of builders. The synergistic supply chain can be considered as an attempt to increase the supply of housing in Australia. This research contributed to rethinking on housing issues beyond the domain of construction for housing policy makers, construction executives, managers, designers and developers. For comprehensive realisation of OSM benefits to Australia, more studies can be developed to verify the results of the prosed strategies. The verified results could lead to future development of OSM particularly in Australia. Adopting OSM housing policies may further require collaboration with planning and legislation research.

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