Offsite Manufacturing in Developing Countries: Current Situation and Opportunities

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Abstract

The mainstream of people living in the developing countries hardly affords a quality house. Housing providers are in a continuous challenge to provide affordable and high quality houses. Offsite manufacturing is a modern method of building houses and has not been widely employed by house builders in developing countries. The house components are produced in offsite factories and transported to the construction site to be assembled. This allows building houses at a controlled environment to ensure high quality, less cost and minimal completion time. An attempt to use offsite manufacturing for improving housing supply in developing countries is presented in this study. It targets the policy makers, developers and designers at the housing sectors in those countries. This paper conducted a systematic review of the literature in 24 developing housing context. Moreover, this paper proposes a leagile supply chain to manage the offsite manufacturing. It is designed to include an integration of lean and agile. Last Planner™ System is used for better coordination among stakeholders. This paper suggests two house building strategies for developing countries. It attempts to include a framework for further research to explore the uptake of prefabricated houses in developing countries.

Keywords: Housing in developing countries, Offsite Manufacturing, leagile supply chain, Last Planner™ System.

Introduction

The construction sector represents a significant part of the Gross Domestic Product (GDP) and employment in most countries. In many developing countries, the construction industry is one of the second largest economic sectors (Preece et al. 2011). The industry commonly includes three broad activities: residential building, non-residential building and engineering construction. More than 50% of the world's population lives in developing countries at high population densities and increasing urbanization (Raftery et al. 1998). Moreover, most of those countries do not have sufficient basic infrastructure to permit rapid economic development. As a result, the supply of houses is inadequate (Preece et al. 2011). The economic-related factors such as consumer price index, changes in the interest and inflation rates are the key driving factors to the demand and supply of houses. Developing countries Government policies, the availability of skilled labor and building materials resources play important roles in the residential building sector. To provide affordable houses within these challenges, some initiatives have been introduced. These

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include Mass House Building Projects (MHBPs) and a sustainable building model for developing countries (Ahadzie et al. 2008). Some initiatives urge for studies of the applicability in transferring the building systems from developed countries to the developing countries. Melchert (2007) reviews the applicability of the Dutch model of sustainable house building to developing countries and finds that the construction sector in developing world remains quite reactive and usually adopting crisis-oriented management approaches. The house building industry suffers from many issues. Many issues are related to quality deficiencies and high production costs of housing. Nevertheless, the house building industry still operates traditionally by focusing on the profits, but not on the house end-user value. As a result, the amplified customer expectations and the international competition, the main driving forces behind changes in house building, are neglected. Improving the house building supply chain is a guarantee to survive in this competitive environment. Some house builders make efforts to improve their performance through inspired ideas from the manufacturing industry, particularly from the production systems i.e. mass customization, lean and agile manufacturing and supply chain management. Applying the manufacturing systems into house building supply chain is referred as offsite manufacturing Hosmer et al. (2013). This application is based on reducing the onsite activities to be undertaken offsite. In this case, it is expected that the activities can be achieved more efficiently in a controlled environment.

Urged by house building issues in developing countries, this paper suggests processes for future research to approach these issues and contribute to housing improvement in these countries. The paper proposes an OSM supply chain based on lean and agile principles. Additionally, the Last Planner™ System (LPS) is reviewed for better coordination among supply chain stakeholders. Although the application of leagile in house building is explained in the previous research of Naim et al. (1999), Childerhouse et al. (2000) and Mostafa et al. (2014). However, these research works have been done in developed countries contexts. Minimal research on applying OSM using lean and agile concepts was found in developing countries. This paper bridges the gap and proposes an OSM supply chain for the housing delivery in developing countries.

Literature Review

Offsite Manufacturing offers several benefits such as improve the onsite safety by providing cleaner and tidier site environment, enhancing finished house quality under factory production, reduce waste generation, shorten house completion time and fewer house construction costs (Goulding et al. 2014). The d house components/modules are produced in offsite factories and transported to the construction site to be assembled. The factory production shows the closest analogy to manufacturing industry. In spite of the benefits of the OSM, the factory physical production has several forms of waste such as waiting time, transportation, inappropriate processing, excessive inventories, defective products and unnecessary motions (Womack and Jones 2011). Moreover, the OSM houses supply chain suffers from several drawbacks such as high initial cost, lack of flexibility in houses design and comprehensive quality control and testing techniques. Furthermore, three major problems appear in using two working locations (onsite and offsite) including broken junction, jumbled jobsite process and vague demands from unclear customers (Chang and Lee 2004). As a result, it leads to slower responsiveness of the house building supply chain.

A supply chain is a network of materials, information, and services processing links with the characteristics of supply, transformation, and demand (Chen et al. 2013). The term supply chain management includes coordination and integration, cooperation among chain members, and the movement of materials to the final customer. In general, OSM supply

chain includes suppliers, manufacturer, transporters, distributors, retailers and customers. The supply chain must be managed to achieve the house end-user. House builders can achieve the house end-user value through maximizing house quality, service level (customer/product support, product service and flexibility to meet customer demands), safety, and sustainability. Whereas, minimizing the house completion time and house construction costs. Lean and agile concepts have the capabilities to adjust the house end-user value through different strategies based on customer demand.

Lean and agile manufacturing concepts are recognized for enhancing the uptake of OSM (Blismas and Wakefield 2009). The key characteristic of lean concept is the waste removal, while agile is the market responsiveness. Lean and agile can be combined within the same supply chain using a decoupling point (Purvis et al. 2014). A combination of the two concepts is called leagile. Previous research confirm that the applying of lean and agile principles facilitate manufacturing through increasing efficiency, improving quality and safety, reducing lead time, reduce human efforts, reduce investment in tools, improving the flexibility and responsiveness (Koskela 1992; Vrijhoef and Koskela 2000). Therefore, lean and agile concepts have potentials for managing the offsite and onsite processes of the house building supply chain.

Research Methodology

To apprehend the housing supply situations in developing countries, the methodology is designed into four phases to systematically collect and analyze the relevant information. A review of background studies and literature was conducted at the first phase of the research. At this stage, opened online databases were explored. Data collection from the databases focused on the current initiatives employed to commonly generate prefabricated house building in developing countries. The range of the search was limited from 1992 onwards to match with the lean concept which has been introduced to the construction sector by Koskela in 1992. The second phase was to explore the application of lean and agile concepts in the prefabricated house building within the data collected from the first phase. This phase included the studies of current application and challenges of lean and agile application in developing countries. The third phase evaluated potentials of applying synergistic supply chain for prefabricated house building. The fourth phase was to construct a proposed model of synergistic supply chain that could contribute to the improvement of housing supply. The model development relied on the data analysis from the previous phases. The methodology framework of this study is demonstrated as in Figure 1.

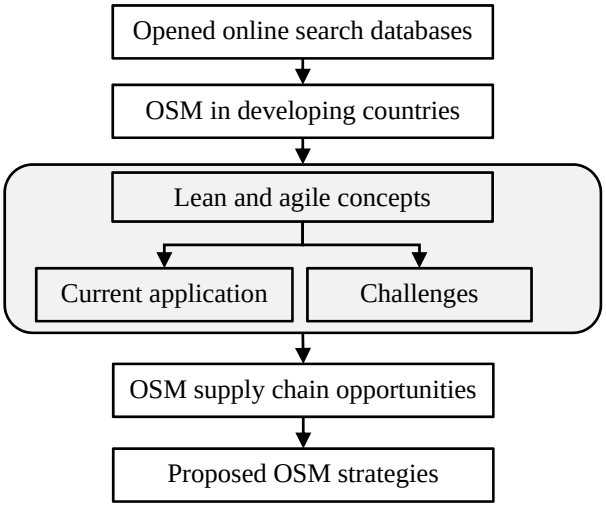

Figure 1. Research methodology framework.

Research findings and Discussion

The opened online search discovered 80 accessible publications from 1992 to 2014 that reflected OSM or prefabricated house building concepts practiced in developing countries namely Bosnia and Herzegovina, Botswana, Brazil, Central African Republic, Chile, China, Columbia, Costa Rica, Egypt, Ghana, India, Indonesia, Iran, Jamaica, Kenya, Nicaragua, Nigeria, Peru, the Philippines, Saudi Arabia, Tanzania, Turkey, Uganda and Vietnam. Out of 78 publications, only 16 articles contained the lean concept. The evidence of using a combination of lean and agile concepts was unlikely to be found in articles of OSM in the developing countries. The findings discovered housing supply situation and the OSM practice in those countries are discussed as following.

House Building in Developing Countries

The growing concentration of people in the developing countries is obvious. Moreover, the increasing rate of urbanizations has accelerated its shelter needs [19]. Therefore, the issues regarding the quality of living environment, water drinking, electricity, sewage systems and waste disposal have been arising. The housing problem is a key factor impacting the quality of living. In some developing countries such as Colombia, Egypt, Ghana, India, Jamaica, and Nigeria, there are a great number of unaffordable houses (Follain and Jimenez 1985; Hubacek et al. 2007; Kolo et al. 2014; Potter and Lloyd-Evans 1998; Tiwari 2001). The majority of people living in the developing countries cannot afford a quality house. The economic and market conditions force them to live in a poor housing quality environment. Housing providers are in a continuous challenge to provide affordable and high quality houses. Housing agencies have invested billions of dollars in innovative urban development projects which are designed to facilitate the supply of adequate housing [19]. Mass House Building Projects (MHBPs) is one of the most established projects of the construction industry in most the developing countries. MHBPs comprise of the largest contributor, up to 60%, to the construction GDP (Ahadzie et al. 2008).

The MHBPs term has derived from the manufacturing sector and it describes the mass production techniques of housing projects. The term consists of some notable characteristics including a requirement for more standardized designs, building domestic residences, no customized construction, sharing of a project location under the same contract conditions (Ahadzie et al. 2008). This type of construction project may aid unmet demand in housing acquisition. The unmet housing demand is not a new issue. The situation in developing countries can be dated back to the work of Follain and Jimenez (1985). Similar situations of unanswered housing demand are mentioned in Tiwari (2001) representing housing building situations in India. It is claimed that the shortage of affordable housing has arisen from the increase of construction costs. With limited support from the government, less innovative housing production, lack of resources control process and shortage of house-building materials and components, the unaffordable housing situations have become critical, especially when high demand and inadequate housing supply create sky-rocketed house prices. Taking all requirements to deliver a massive house building project and the shortage of housing supply into account, the idea of prefabricated housing systems can be employed to improve the situations. When the system is effectively operated, it enables the increase in housing supply that can fulfil the housing shortage.

OSM Situation in Some Developing Countries

OSM in China

The OSM is known in China as Industrialized Building (IB). It is agreed through many research that IB have a key role in the Chinese residential development due to its benefits

in improving quality, productivity, cost- effectiveness, safety and sustainability(Zhang et al. 2014). However, the uptake of prefabricated was found limited due to the lack of understanding the potential benefits of prefabricated houses. The challenges of the prefabrication technology in China were persistently mentioned. The key challenges included lack of manufacturing capability, product quality problems and lack of supply chain (Arif and Egbu 2010). It was to argue that any achievement of these challenges would provide a fundamental development for local construction sectors for future implementation of prefabrication.

OSM in India

In India, a growing demand for housing was reported. The projected demand was nearly 27 million houses required by 2012. It was noted that 99% of these houses were needed by households in the lower income group (RCIS 2011). Therefore, the Indian Government and construction/ manufacturing industries embraced a high volume of housing production with high quality. India has established prefabricated and modular technologies in its construction sector. The India Concept House (ICH) represents construction of affordable housing using prefabricated technology. ICH is considered as an innovative prefabricated housing solution that could help to achieve cost savings (range of INR 900-1200 per sq. ft.) and reduce construction time by 90%. The prefabricated building system enables a 23 square meter house to be built in four weeks and 93 square meter house to be built in six weeks. The ICH conceives as both a dwelling for inhabitation and as a process by which houses are produced through a managed supply chain. ICH designed as 23, 46, 70 and 93 square meter increments that facilitating expansion from one room to four rooms. The prefabricated houses are generally considered as cost effective, quick to assemble and sustainable. However, the maturity of prefabricated technology was found to be steadily developing. It was suggested that the improvement to prefabrication maturity should include the whole supply chain of prefabricated house building (RCIS 2011).

OSM in Malaysia

The research found that the prefabricated house building in Malaysia has reached market maturity. The Malaysia Government has adopted the Industrialized Building Systems (IBS) in the housing projects to improve delivery timing, and producing affordable and quality houses (CIDB 2012). Besides adopting IBS, the government has well established IBS legislation and building codes to enhance the uptake of high quality prefabricated houses for the construction sector. Nevertheless, supply chain integration was urged to maintain the competency of future house building supply (Azman et al. 2010).

OSM in Tanzania

Kalokola (2014) mentioned that prefabricated houses are still rarity in East African countries. Mwamila and Karumuna (1999) studied the advantages of applying semi-prefabricated concrete construction techniques in the Tanzanian housing industry. The highlighted benefits included saving of up to 19% of direct total costs and reducing construction time up to 57%. The concept of prefabricated house building started in Dodoma, the capital of Tanzania, in 2013. The Capital development authority was in charge of planning and development. This conceptual idea aimed to deliver many low cost houses within a short period. Future studies on this project may shade new light to Tanzanian housing growth and house quality development.

OSM in Egypt

The Egyptian housing sector has been encountering a shortage of supplying affordable houses for the low-income group of population. The Central Agency for Public Mobilization and Statistics (CAPMAS) reported shortage of around 40,000 dwellings

annually (CAPMAS 2013). The factors contributing to the situation can be classified into economic, legislative, social and construction methods. Although there is considerable concern over the housing situation, the combined efforts of both public and private sectors have struggled to meet the growing demand. Addressing the shortage situation by suggesting new construction methods and building materials were found to be minimal. The OSM in the Egyptian context was found under the name of prefab. It was found that the experience of prefab in Egyptian context only limited to caravan offices or precast concrete. The market of prefab is only produce temporary offices and caravans for the major infrastructure projects or precast buildings (Arabian Construction House for Prefab Building 2014).

OSM in Nigeria

Kolo et al. (2014) stated that the OSM in Nigeria still gradually emerging based on learning from other developed countries. They highlighted the core OSM uptake barriers in Nigeria including reluctance to innovate, paucity of codes and standards, supply chain integrations, and skill requirements. To address these barriers, governmental support is a pivotal in helping to establish OSM as a viable alternative to traditional approaches. They observed the need to encourage the awareness of OSM should be through better government policies, and through skilled supply chain partners.

OSM in Saudi Arabia

The awareness of prefabrication technology was positive in the construction sector in Saudi Arabia. The prefabrication technologies were found limited to concrete components used in building bridges, wall and façade panels for multistory buildings, and temporary structures such as site offices and portable toilets. The concept of prefabrication was not well-accepted as a key part of construction processes. The growth of manufacturing sector and the promotion of construction- related-manufacturing were considered as possible ways of increasing the adoption of prefabrications technology in Saudi Arabia (Aburas 2011).

Lean and Agile Concepts for OSM

Lean concept origins are traced to Toyota Production System (TPS). Lean concept has significant interest in the construction sector since Koskela (1992) has conceptualized in three corresponding ways namely transformation of materials into building structures, flow of materials and information through various building processes, and value generation and creation for customers through the elimination of value loss. Lean construction can be defined as a model of building production management based on production management theory. It aims to make the value stream as the centre in the delivery process of construction project by using the professional skills and methods to achieve maximisation of the customer value and minimisation of waste (Abdelhamid et al. 2008). Lean construction practices include pull system, visual management, continuous improvement, Last Planner System (LPS), 5S process, reduce batch size, standardise work structuring and error proofing.

The initiative of agile construction was established in direct response to the Latham report (Lee 2003). The report highlighted the UK construction industry requirement to reduce the construction cost by 30% by the year 2000. To achieve this target the whole industry needed to change. Benchmarking was one method to stimulate the required change in the construction practices. Agile construction exemplifies the characteristics of visibility, responsiveness, productivity and profitability. Agile comprises some management tools such as virtual enterprise, concurrent engineering, information

technology (i.e. Computer Aided Design/Computer Aided Manufacturing (CAD)/ (CAM)) (Daneshgari 2010).

Integration of lean and agile is the best solution to answer all the production issues in the world class market competition (Purvis et al. 2014). Combining lean and agile within the whole supply chain can be accomplished by using the decoupling point and known as leagility. In general, the decoupling point separates the supply chain into lean in the upstream and agile in the downstream. Lean concept is the suitable alternative where there are high volume, low variety, and low predictable change environment. Agile concept is the appropriate where there are high variety, low volume, and high predictable change environment.

OSM House Building for Developing Countries

The prefabricated house building supply chain can be visualized as shown in figure 2. It comprises the suppliers, offsite factory, contractors/sub-contractors, construction site and customers. The Last Planner™ System (LPS) is used to establish a better coordination among supply chain stakeholders. LPS is used to transfer planning responsibility between construction organization management and the field persons. The system facilitates the workflow so that labor and material resources can be more productive (Forbes and Ahmed 2011). LPS encompassing four levels of planning processes with different consecutive spans: master scheduling, phase scheduling, Look-ahead Planning (LAP), and Weekly Work Planning (WWP).

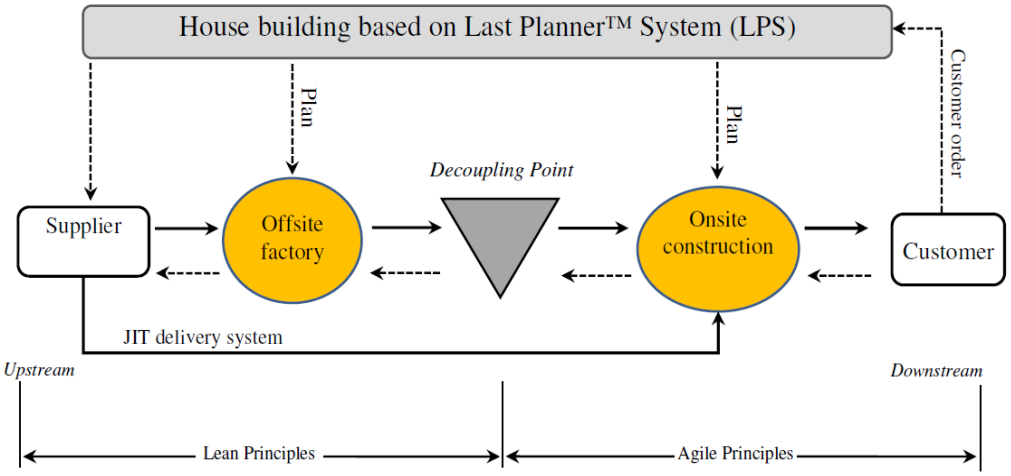

Figure 2. OSM house building supply structure.

Master schedule is describing 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 (Hamzeh et al. 2012)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 organizations 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 (Ballard and Howell 2004). WWP represents the most detailed plan in the LPS showing interdependence between the works of various specialist organizations. 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. Analyzing reasons for plan failures and acting on these reasons is used as the basis of learning and continuous

improvement. This paper suggests two decoupling point positions to manage the OSM supply chain for achieving the house customer demands in the developing countries. Each position is suitable for a house building strategy.

Build to Stock Strategy

The first decoupling point is located after the onsite construction activities and finished house building. The houses are designed and built to meet low income group. In this strategy, the governments of developing countries could ensure its capacity to serving large-size accommodation projects within the contracted timeframe. Therefore, the activities before selling should be lean to fit the costs. Agile is suitable after the decoupling point to diminish the delivery time, meet the customer satisfaction and speed of return on investment.

Self-Building Strategy

In the second strategy, the decoupling point is located at house components suppliers. This strategy is suitable for the self-building houses which a homeowner is closely involved in every aspect of the house building. This strategy is developed on a similar concept of the house building and the personal computer assembly. The house customers are at their own responsibilities to hire builders to assist them with some onsite construction activities. The key role of prefabricated house building organization is to supply the house modules and components to the suppliers. House building organizations should aim at making the house designs as simple as possible. The organizations should provide variable 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 self-build house suppliers.

Conclusions

Offsite manufacturing has been introduced to increase housing affordability in developing countries. The employment of OSM can be recommended to any building organizations that search for more efficient and responsive strategies to meet growing house demands. In house building sector of developing countries, combining lean and agile concepts may require more study to examine their effect on time reduction and cost overrun. The cutting-edge knowledge in manufacturing sector may provide potential improvement of OSM systems needed by the sector. In a broader sense, the system can be seen as an attempt to increase the supply of affordable housing. Two strategies of OSM systems have been proposed as solutions to enhance the delivery of housing in developing countries. These strategies are built to stock and self-building house.

Limitations and Suggestion for Future Research

This paper has been constructed using the existing databases related to OSM in the context of developing countries. The proposed OSM supply chain strategies could be formed a framework for further research relating to OSM in developing countries. As such, it may be useful for housing policy makers, construction executives, managers, designers, developers and scholars to rethink about housing issues by conducting future empirical research within and beyond the domain of construction. For comprehensive realization of OSM benefits to developing countries, more research that rooted in understanding the theory of manufacturing and construction is strongly recommended. Moreover, adopting OSM policies requires collaboration with planning and legislation research.

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