SYNERGISTIC SUPPLY CHAIN FOR PREFABRICATED HOUSE BUILDING IN DEVELOPING COUNTRIES

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ABSTRACT

The majority of people living in the developing countries hardly afford a quality house. The economic and market conditions force them to live in a poor quality house. Housing providers are in a continuous challenge to provide affordable and high quality houses. A prefabricated house is a new 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 prefabricated houses 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. The paper proposes a synergistic supply chain to manage the prefabricated house building supply chain. The factory production of house components shows the closest analogy to manufacturing industry. Moreover, the house customer requirements on house quality, price and completion time make the design specifications difficult that leads to slow response to achieve customer demand. Therefore, the synergistic supply chain is designed to include an integration of lean and agile (leagile). Last Planner™ System is used for better coordination among stakeholders. This paper suggests two locations of decoupling point with two house building strategies. It attempts to include a framework for further research to explore the uptake of prefabricated houses in developing countries.

Keywords: Prefabricated houses, housing in developing countries, synergistic supply chain, Last Planner™ System, leagility; supply chain management.
I. INTRODUCTION

The construction sector usually 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 [1]. Construction industry generally includes three broad areas of activity: 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 urbanisation [2]. 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 [1]. The economic-related factors such as consumer price index (CPI), changes in the interest rates and inflation are the key driving factors to the demand and supply of houses. Developing countries government policies, the availability of labour 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 include Mass house building projects (MHBPs) and a sustainable building model for developing countries [3-4]. Some initiatives urge for studies of the applicability in transferring the building systems from developed countries to the developing countries. Melchert [4] 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 building organisations make efforts to improve their performance through inspired ideas from the manufacturing industry, particularly from the production systems (e.g. mass customisation, lean and agile production) and supply chain management. Applying the production systems into house building supply chain is referred as prefabricated house building. This application is based on simplifying and reducing the house onsite activities to be done in offsite factory. 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 a synergistic house building 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 agile in house building is explained in the previous research of Naim et al. [5], Childerhouse et al. [6] and Mostafa and Dumrak [7]. However, these research works have been done in developed countries contexts. Minimal research on applying prefabricated house building using lean and agile concepts was found in developing countries. This paper is structured in seven sections. After introduction, the second section reflects review of related literature to house building issues in developing countries. The third section contains the research methodology. The fourth section highlights the research findings. The fifth summarised the application of lean and agile concepts in construction. The sixth section introduces the synergistic house building supply chain and its proposed framework. The final section presents the conclusions and recommendations for further research.
II. LITERATURE REVIEW

Prefabrication technology 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 [8-9]. The prefabricated 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 prefabrication, the factory physical production has several forms of waste (non-value added activities). Ohno [10] enumerates seven forms of waste that found in factories physical production such as overproduction, waiting time, transportation, inappropriate processing, excessive inventories, defective products and unnecessary motions. Moreover, the prefabricated 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 [11]. 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 [12]. As a result, it leads to slower responsiveness of the house building supply chain.

A supply chain consists of all parties that directly or indirectly try to fulfil a customer demand. In general, prefabricated supply chain includes suppliers, manufacturer, transporters, distributors, retailers and customers. Chen et al. [12] exemplify supply chain as a network of materials, information, and services processing links with the characteristics of supply, transformation, and demand. Moreover, the term supply chain management (SCM) includes coordination and integration, cooperation among chain members, and the movement of materials to the final customer. Stock and Boyer [13] provide an encompassing definition for SCM as the management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final customer with the benefits of adding value, maximising profitability through efficiencies, and achieving customer satisfaction. Therefore, house building supply chain could be visualised as shown in Fig. 1.

![Diagram of Prefabricated House Building Supply Chain](image-url)

**Figure 1.** Prefabricated house building supply chain representation.
The house building supply chain must be managed to achieve the house end-user value presented in equation 1.

\[
\text{House end-user value} = \frac{\text{House quality} \times \text{House service level}}{\text{House construction costs} \times \text{House completion time}}
\]

Equation (1)

House builders can achieve the house end-user value through maximising house quality, service level (customer/product support, product service and flexibility to meet customer demands), safety, and sustainability. Whereas, minimising 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. The synergistic house building supply chain is designed to include the excellence practices of lean and agile concepts (Fig. 2). Lean and agile principles are recognised as the top concepts for world class manufacturing [14]. 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 [15]. 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 [16-18] Therefore, lean and agile concepts have potentials for managing the offsite and onsite processes of the house building supply chain.

III. METHODOLOGY

To apprehend the housing supply situations in developing countries, the methodology is designed into four phases to systematically collect and analyse 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 Fig 2.
IV. RESEARCH FINDINGS AND DISCUSSION

The opened online search discovered 78 accessible publications from 1992 to 2014 that reflected 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, Tanzania, Turkey, Uganda and Vietnam. Out of 78 publications, only 15 articles contained the lean concept. The evidence of using a combination of lean and agile concepts was unlikely to be found in articles of prefabricated house building in the developing countries. The findings revealed housing supply situations and the practice of prefabricated house building in those countries are discussed as follows:

IV.1. HOUSE BUILDING IN DEVELOPING COUNTRIES

The growing concentration of people in the developing countries is obvious. Moreover, the increasing rate of urbanisations 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 China, India, Uganda, Colombia, Korea, Philippine, Jamica and Ghana, there are a great number of unaffordable and non-liveable houses [19-24]. 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 [3].

The MHBPs term has derived from the manufacturing sector and it describes the mass production techniques of housing projects [22]. The term consists of some notable characteristics including a requirement for more standardised designs, building domestic residences, no customised construction, sharing of a project location under the same contract conditions [3]. 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 [19]. Similar situations of unanswered housing demand are mentioned in [21] 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.

IV.II. Prefabricated housing in developing countries

The research findings from literature exploration on prefabrication housing in developing countries revealed that some developing countries such China has potentials to use prefabricated technology in its own internal markets. The prefabrication technology is known in China as Industrialised 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 [25-28]. However, the uptake of prefabricated was found limited due to the lack of understanding the potential benefits of prefabricated houses [29]. 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 [25-28]. It was to argue that any achievement of these challenges would provide a fundamental development for local construction sectors for future implementation of prefabrication.

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 [30]. 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 [30]. 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 [29]. However, the maturity of prefabricated technology was found to be steadily developing [30]. It was suggested that the improvement to prefabrication maturity should include the whole supply chain of prefabricated house building [29].
The research found that the prefabricated house building in Malaysia has reached market maturity. The Malaysia Government has adopted the Industrialised Building Systems (IBS) in the housing projects to improve delivery timing, and producing affordable and quality houses [31]. 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 [32].

Kalokola [33] mentioned that prefabricated houses are still rarity in East African countries. Mwamila and Karumuna [34] 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 shed new light to Tanzanian housing growth and house quality development.

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 multistorey 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 [35].

V. LEAN AND AGILE CONCEPTS IN CONSTRUCTION

Lean concept origins are traced to Toyota Production System (TPS) [36]. Lean concept has significant interest in the construction sector since Koskela [16] has presented the Transformation, Flow and Value (TFV) theory in construction. In TFV theory, construction is conceptualised 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 [37]. Lean construction practices include pull system, visual management, continuous improvement, reduce batch size, standardise work and error proofing [38] (Sacks, 2010).

Agile concept on the other hand became popular in 1991 by a group of scholars at Lehigh University in USA. Sharifi and Zhang [39] state that new competitive environment is the key driver for change in manufacturing. The competition criteria are continuous improvement, rapid response, and quality improvement. The initiative of agile construction was established in direct response to the Latham report [40]. 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 [40] (Lee 2003). 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)) [41].

To survive in competition in the world class markets, the organisations should focus on factory and markets. This can be accomplished by hybridising lean and agile concepts for the supply
chain through decoupling point that is known as leagility. Naylor et al. [42] define leagile as the combination of the lean and agile concepts within a supply chain strategy by positioning the decoupling point so as to best suit the need for responding to a volatile demand downstream yet providing level scheduling upstream from the decoupling point. For competition, Christopher and Towill [15] emphasis that supply chains must be in touch with market demand changes which can be divided into three critical dimensions: variety, variability and volume. Lean concept is best for high volumes, low variety and predictable change in environment. Agile concept is best where there are high variety, low volume and less predictable change in environment. The real demand visibility is limited in most supply chains. Accordingly, supply chains might be lean up to decoupling point and agile beyond decoupling point.

Decoupling point is the point at which market pull meets upstream push. Agility beyond decoupling point is explained by the principle of postponement by using generic or modular inventory to postpone the final commitment, where final assembly or customisation depends on real demand. In this paper, two positions for decoupling point, developing two house building strategies, are suggested to suit the house building in the developing countries. The first location is suggested to place the decoupling point at the end of the supply chain towards the customer (see Fig. 3). In this case, the house building strategy is built to stock. The second position is suggested to be at the house components suppliers which support self-building house strategy. The two positions and strategies are discussed in the following section to support the proposed synergistic house building supply chain that can be undertaken in developing countries.

VI. PROPOSED SYNERGISTIC HOUSE BUILDING SUPPLY CHAIN FOR DEVELOPING COUNTRIES

The prefabricated house building supply chain can be visualised as shown in Fig. 3. 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 as demonstrated in Fig. 4. LPS is used to transfer planning responsibility between construction organisation management and the field persons [43]. The system facilitates the workflow so that labour and material resources can be more productive [44]. LPS encompassing four levels of planning processes with different consecutive spans: master scheduling, phase scheduling, Look-ahead Planning (LAP), and Weekly Work Planning (WWP).

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 [45]. 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 [46]. 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 [45]. 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 [43].
This paper suggests two decoupling point positions to manage the synergistic supply chain for achieving the house customer demands in the developing countries. Each position is suitable for a house building 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.

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 [47]. 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 organisation is to supply the house modules and components to the suppliers. House building organisations should aim at making the house designs as simple as possible. The organisations 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.

VII. CONCLUSION

Prefabricated housing technology has been introduced to increase housing affordability in developing countries. The employment of prefabricated technology can be recommended to any building organisations that search for more efficient and responsive strategies to answer growing house demands. In house building sector of developing countries, synergising lean and agile concepts may require more study to examine their effect on time reduction and cost overrun. The sector is a part of construction industry which lies under residential building section. Any studies undertaken within the construction industry may provide common knowledge that could be related to house building. The cutting-edge knowledge in manufacturing sector may provide potential improvement of prefabricated systems needed by the house building sector. It is beneficial to this research to scrutinise the existing problems that generally occur in the construction industry with an assumption that house building sectors in developing countries are likely to share similar experience.

A synergistic house building supply chain has been proposed to enhance prefabricated house building in developing countries. The synergistic supply chain includes two house building strategies: built to stock and self-building house. It could be considered as a framework for further research relating to prefabricated houses in those countries. In a broader sense, the synergistic supply chain can be seen as an attempt to increase the supply of affordable housing in the developing countries. As such, it may be useful for housing policy makers, construction executives, managers, designers and developers to rethink about housing issues beyond the domain of construction. For comprehensive realisation of prefabricated house benefits to developing countries, more research that rooted in understanding the theory of manufacturing and construction is strongly recommended. Moreover, adopting prefabricated housing policies requires collaboration with planning and legislation research.

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