LEAGILE SUPPLY CHAIN FOR AUSTRALIAN INDUSTRIALISED HOUSE BUILDING

Sherif Mostafa[1] and Jantanee Dumrak[2]

ABSTRACT

The 2012 Australian National Housing Supply Council (NHSC) reported a constantly growing demand for new houses in many capital cities around Australia. Since then, the supply of housing has not responded commensurately to the growing demand. The residential sector challenges this issue by developing and effectively using new materials, processes, and practices to strengthen their competitive advantage against other construction sectors. This paper gives an overview of the Australian housing supply and demand. House builders have been adopting the idea of producing house modules and elements in factories. Therefore, the house building has been changed from traditional to prefabricated supply chain. Managing the prefabricated houses supply chain is playing an important role in the housing supply.

A leagile supply chain is introduced to manage the prefabricated supply chain. It employs material and information decoupling points. Four strategies are introduced to balance the trade-offs between the housing supply and demand. Applying any strategy is guided by the factors affecting the housing supply and demand. The three main factors are the house completion time, cost of finished house, and customer preferences. In this paper, the Analytical Hierarchy Process (AHP) is introduced as a facilitator to the supply chain strategies selection in the Australian housing industry. The AHP model takes the three factors into account for differentiating between the four supply chain strategies. The model was implemented with the aid of the commercial software package known as Expert Choice©. The results from the AHP model show the benefits of each strategy with respect to the factors tested.

KEYWORDS

Housing Australia, Supply chain management, Leagile, Decoupling point, AHP.

INTRODUCTION

The construction industry represents a significant part of the Australian Gross Domestic Product (GDP). It was the fourth largest contributor to GDP (6.8%) during 2008-2009 (ABS 2010). The Australian construction industry includes both the private and public sectors that are engaged in three broad areas of activity: residential building, non-residential building, and engineering construction. The statistics showed that the values of work commenced in residential building seem to be less responsive to the industry growth. The situation might be resulted by economic-related factors such as population growth, and changes in interest and inflation rates in addition to the government policies such as Australian energy consumption and carbon-tax policy (Ren et al. 2011), the availability of resources, such as labour and

1 School of Natural and Built Environments, University of South Australia, 5001 SA, Australia
2 School of Natural and Built Environments, University of South Australia, 5001 SA, Australia

building materials. To react to the existing challenges while remaining competitive against other construction sectors, more research leading to further development and effective use of innovative materials, processes, and practices is recommended (Thorpe and Ryan 2007).

A supply chain (SC) is a network of materials, information, and services processing links with the characteristics of supply, transformation, and demand (Chen and Paulraj 2004). Stock and Boyer (2009) refer to the supply chain management (SCM) roles as coordination and integration, cooperation among chain members, and a movement of materials to the customer. Vrijhoef and Koskela (2000) support the application of SCM in the construction industry. The prefabricated houses have been adopted in the housing industry (Tam et al. 2007). The prefabricated house building SC is involved in on- and off-site operations. The off-site factories are used to produce the house modules and then transported to be assembled at the construction site (Vrijhoef and Koskela 2000). Christopher and Towill (2001) emphasise that SCs are competing in the market, not just the organisations which employ the SC. Customer value determines success or failure of an SC in the market place. Customer preferences on house design, quality, cost, safety, and completion time make the design specifications become more complex. It leads to slower responsiveness of the house building SC. Moreover, the myopic control of off- and on-sites leads to waste problems (Vrijhoef and Koskela 2000).

Lean and agile are recognised as the top manufacturing paradigms to run an SC. The key characteristic of lean is the waste removal, while for agile is the market responsiveness (Cudney and Elrod 2011). Lean and agile can be combined using the decoupling point called as leagile SC (Christopher and Towill 2001). Previous research studies confirm that the application of lean and agile principles facilitate construction processes through improving quality and safety, reducing lead time, reduce investment in tools, improving the flexibility and responsiveness (Koskela 1992, Owen et al. 2006, Chen et al. 2007). Therefore, lean and agile concepts have potentials for managing the house building SC. This paper contributes to the knowledge on how lean and agile concepts can be employed in the Australian house building SC. Herewith, the application of leagility is explained and builds upon the previous research of Naim et al. (1999), Childerhouse et al. (2000), and Vrijhoef and Koskela (2000).

OVERVIEW OF AUSTRALIAN HOUSING

The Australian housing supply has not kept pace with the growing demand especially in capital cities (COAG 2012). This issue has been confirmed by the housing industry alliances such as the NHSC, Housing Industry Association (HIA), and Master Builders Association (Dalton et al. 2011). The report on *Housing to 2020* produced by HIA (2011) indicates the gaps between housing demand and supply over the periods until 2020. It is forecasted that in 2016 the difference between demand and supply will reach 543,300, 372,100 and 213,200 dwellings in low, medium, and high build rate respectively. At the year 2020, the expected shortage of dwellings will be 808,900, 500,900, and 214,700 in respect to the different scenarios predicted.

The Australian housing undersupply is influenced by both housing supply and demand. The housing supply factors include *house cost*, *house completion time, and house customisation.* The house cost refers to residential construction costs, taxes on new housing and land release (HIA 2011, NHSC 2012). The completion time indicates the quality of housing delivery. There is an increase in the average Australian house completion time, while the production rate has found to be relatively stable (Gharaie 2011). The average Australian house completion time has risen from 1.8 quarters to 2.4 quarters from 2000 to 2008 (ABS 2008). On the demand-side, the Australian housing is influenced by other factors such as demographic and house customisation. Demographic factors include population growth, net overseas migration, and household size/formation rates (COAG 2012). *House customisation* means customising the house design to suit the customer requirements (NHSC 2012).

PREFABRICATED HOUSE BUILDING SUPPLY CHAIN

Prefabrication has been adopted recently in the house building industry. The prefabricated house building carried out at two working sites ‘off-site and on-site’. The house modules are produced in the off-site factories and transported to the construction site to be assembled (Vrijhoef and Koskela 2000). Prefabrication offers several benefits such as improving on-site safety by providing cleaner and tidier site environment, enhancing quality under factory production, reducing waste generation, shortening lead time and eliminating on-site malpractices (Tam et al. 2007).The factory production of prefabricated house modules shows the closest analogy to manufacturing (Höök and Stehn 2008). However, the customer and supplier relations are the two main features that distinguish house building from manufacturing.

In spite of the benefits of the prefabrication, the factory physical production has several forms of non-value added activities or wastes. Ohno (1988) enumerates seven forms of waste that found in factories physical production such as over-production, waiting time, transportation, over-processing, excessive-inventories, defective products, and unnecessary movement. Moreover, the prefabricated house customisation makes the design specifications become more complex. As a result, it leads to slower response to achieve customer requirements. Furthermore, three challenges for construction technical change towards employ two sites. The first challenge is the broken junction between the off-site and on-site activities. The second is the jumbled on-site processes due to difference between the production flow at off-site factories and construction flow on-site. The third challenge is the vague demands from unclear customers (Chang and Lee 2004).

There are some attempts to address these problems through introducing lessons from the manufacturing industry to house building, particularly lean and agile concepts, and SCM (Naim et al. 1999, Childerhouse et al. 2000, Green et al. 2005, Höök and Stehn 2008). An SC consists of all parties that directly or indirectly try to fulfil a customer demand. The prefabricated house building SC can be visualised as shown in Figure 1. It comprises the suppliers, warehouses, off-site factory, contractors/sub-contractors, construction site, and retailers/customers. The SCM controls the off-site and on-site. It has four roles: improving the interface between site activities and SC, improving the SC, transferring activities from the site to the SC, and integrating off-site and SC (Vrijhoef and Koskela 2000). The prefabricated housing SC must be managed to achieve the customer value. It can be attained from maximising house customisation by employing agile concept. Besides, the house completion time and cost can be minimised by employing lean concept.

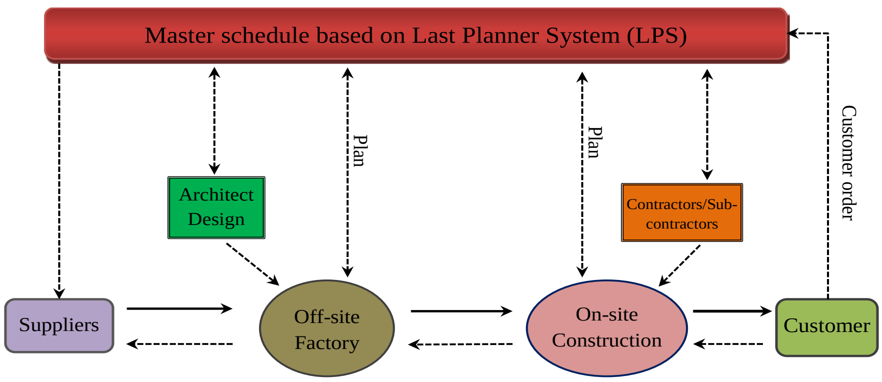

Figure 1: Conceptual model of prefabricated house building SC.

LEAN, AGILE, AND LEAGILE SUPPLY CHAIN

There are three approaches to operate an SC; lean, agile, and Leagile (Christopher and Towill 2000). Lean approach was first developed in the Toyota production system (TPS). Lean comprises of management practices that can be applied to eliminate the waste (Shah et al. 2008). Lean thinking application into the construction environment was first discussed by Koskela in 1992 (Mossman 2009). The transformation-flow-value (TFV) concept of production has been developed by Koskela (1992) as a new perspective to improve the construction performance. In the TVF concept, the construction production consists of three corresponding processes: a transformation of materials into standing structures, a flow of the materials and information through various production processes, and a value creation for customers through the elimination of value loss (Bertelsen 2002).

Agile concept on the other hand became popular in 1991. Sharifi and Zhang (1999) state that new competitive environment is a key driver for changes 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 (1994 cited in Lee 2003). The report highlighted the UK construction industry requirement to reduce the construction cost by 30% by the year 2000. Naim et al. (1999) suggest the employment of agile principles in the construction SCs to achieve profitable opportunities in dynamic markets. Agile construction exemplifies the characteristics of visibility, responsiveness, productivity and profitability (Daneshgari 2009).

Integration of lean and agile is the best solution to answer all the production issues in the world class market competition (Agarwal et al. 2006). Combining lean and agile within the whole SC can be accomplished by using the *decoupling point* (DP) and known as *leagility*. The leagility term was firstly introduced by Naylor et al. (1999). In general, the DP separates the leagile SC into lean in the upstream and agile in the downstream (Mason-Jones and Towill 1999). For competition, Christopher and Towill (2000) emphasise that SCs must be in touch with market demand changes which can be divided into three critical dimensions; variety, variability (or predictability), and volume. Lean concept is the best alternative where there are high volume, low variety, and low predictable change environment. Agile concept is the best option where there are high variety, low volume, and high predictable change environment. The real demand visibility is limited in most SCs. The SCs may be lean prior to DP and agile beyond DP.

There are two DPs in the leagile SCs; *material DP* which ideally should lie as far down stream as possible as well as close to the final marketplace. *Information DP* should lie as far upstream as possible in the SC. Sometimes information DP is called customer order decoupling point (CODP) (Wikner and Rudberg 2005). Agility beyond decoupling point is explained by the principle of postponement by using a generic or modular inventory to postpone the final commitment, where the final assembly or customisation depends on real demand. Leagile SC has capabilities to achieve the house end-user value through different strategies according to the CODP. The leagile house building SC mainly focuses on waste removal and responsive mechanisms through applying the excellence lean and agile practices.

LEAGILE HOUSE BUILDING SUPPLY CHAIN STRATEGIES

The previous research of Childerhouse et al. (2000) and Naim and Barlow (2003) were based on using material DP in the UK house building SC. In this paper, the leagile house building SC employs both information and material DP. The material DP is the stocking point of finished house modules or components. The information DP is the point where the customer demand enters the value chain. There are four alternative positions for the DPs which are suggested to be employed in Australian house building SC.

In **Make to Stock (MTS)** strategy, both material and information DP are located after the on-site construction activities and house building finished. This strategy is also known as ‘specs’. The houses are designed and built ‘speculatively’ based on the builders’ catalogue (Naim et al. 1999, 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 DP to diminish the delivery time. As a result, the customer satisfaction and the speed of return on investment (ROI) occur (Childerhouse et al. 2000).

In **Built to Order (BTO)** strategy, the material and information DPs are positioned at the off-site factory. The customer houses will be built according to the builder’s catalogues. A variety of houses designs are included in the catalogues. The customers have a degree of customisation 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 later will do the construction activities on-site 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 off-site factories. Agile will be employed in stages of shipments and on-site construction to ensure more responsiveness in delivering the houses.

In **Design to Order (DTO)** strategy, the customer demand enters the value stream at the design stage. Therefore, customers have a relatively high degree of customisation. They can specify the design of their 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 off-site factories, whilst the other activities need to be more agile.

The final strategy is **outsourcing to suppliers (OTS)**. This strategy is suitable for the self-building houses which 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 (Naim and Barlow 2003). The Australian housing is produced by small to large organisations. In 2009, the largest 100 builders commenced about 37 per cent of all residential dwellings (Dalton et al. 2011). This proportion indicated that 63 per cent of all residential have been constructed by small builders or in the form of self-building houses. In Victoria state, the Department of Human Services (2011) introduces *group self-build* initiative to support individuals to build their own houses. The group usually consists of 12 homes within or nearby area. Each group of participants receives a bridging loan from the director of housing to purchase land and build their houses. The customers need to hire an architect for house designing and builders to assist them with some onsite construction activities. Therefore, the key role of house building organisations is to supply the house modules and parts to the suppliers. House building organisations should aims to make the house designs as simple as possible. The organisations must have 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.

OPTIMISING HOUSE BUILDING SUPPLY CHAIN STRATEGIES

In this paper, it is found that the housing supply and demand factors mentioned earlier contribute to the undersupply of Australian housing. Moreover, the factors impact on the selection of house building SC strategies. The AHP approach can be used to evaluate and rank the house building strategies. It is a multiple-criterion decision making developed by Saaty (1980) using multi-level hierarchical structure of goal, criteria, and alternatives. The objective of AHP is to find the SC strategy that is the most suitable for each factor, or a combination of factors. The Expert Choice© software has been developed to support AHP. This software has advantages including a user friendly environment, an evaluation of inconsistency index of assessments, and a sensitivity analysis of results. It is to be reminded that the criteria considered in the AHP model are the three factors: house completion time, house cost, and house customisation. The four house building strategies suggested in this paper are considered as the alternatives used in the model. The AHP model developed using Expert Choice© is shown in Figure 2. The first level was set as the goal of the model. The second level consisted of the three criteria. The four strategies were placed at the bottom level of the hierarchy as decision alternatives.

After constructing the AHP model, pairwise comparisons between the model's elements '*goal, criteria and alternatives*' at all levels were conducted using nine point scale developed by Saaty (1980). Pairwise comparisons were performed systematically in two stages. The first stage included the combinations of criteria and goal relationships. The criteria were compared according to their relative importance with respect to the goal. In the second stage, alternatives were compared according to their relative importance with the respect to criteria.

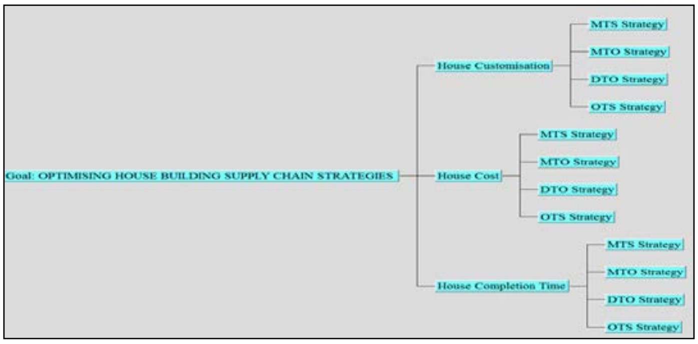

Figure 2: The structure of AHP model for house building SC in Expert Choice©.

The validity of the pairwise comparisons process was performed using the AHP consistency test. This process was carried out through the determination of inconsistency index of the pairwise comparisons which could be calculated in the Expert Choice© software. In general, the inconsistency index less than 0.1 indicates a satisfactory degree of consistency. Afterwards, the AHP priorities were generated using Expert Choice© software. Figure 3 presents an example of pairwise comparison between MTS and MTO strategies with respect to house customisation.

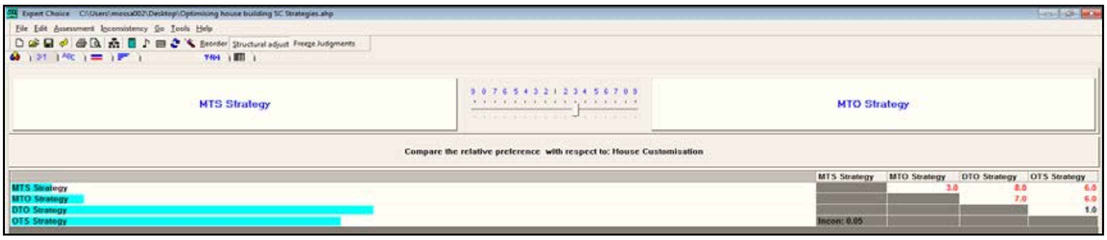

Figure 3: Example of pairwise comparison.

After pairwise comparisons, the local priorities were synthesised from the goal and the overall priorities were calculated. The overall priorities of the four house building strategies are presented in Figure 4. From the test results, the OTS strategy was considered the best alternative which received the highest rating of 0.388. The second best strategy was the MTS which scored 0.308, followed by DTO with a score 0.189. The last one was MTO strategy with a score of 0.115.

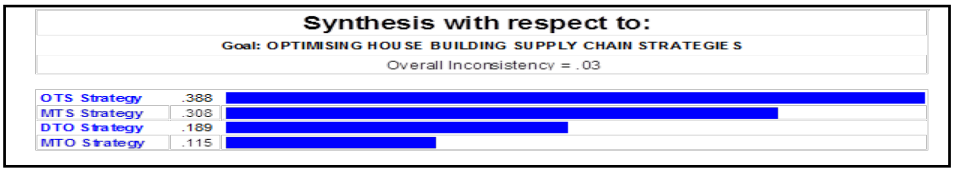

Figure 4: Overall priorities of alternatives in distributive mode.

Finally, sensitivity analysis was performed to generate the results of optimisation. Figure 5 shows a summary of the performance of each house building strategy interacting with each factor. The factors contained weighted percentage from 0 to 100 per cent. Changing the weight could change the ranking of the strategies. At the maximum percentage (100%), house customisation, house cost, and house completion time factors generated the best results for DTO, MTS, and OTS strategy respectively.

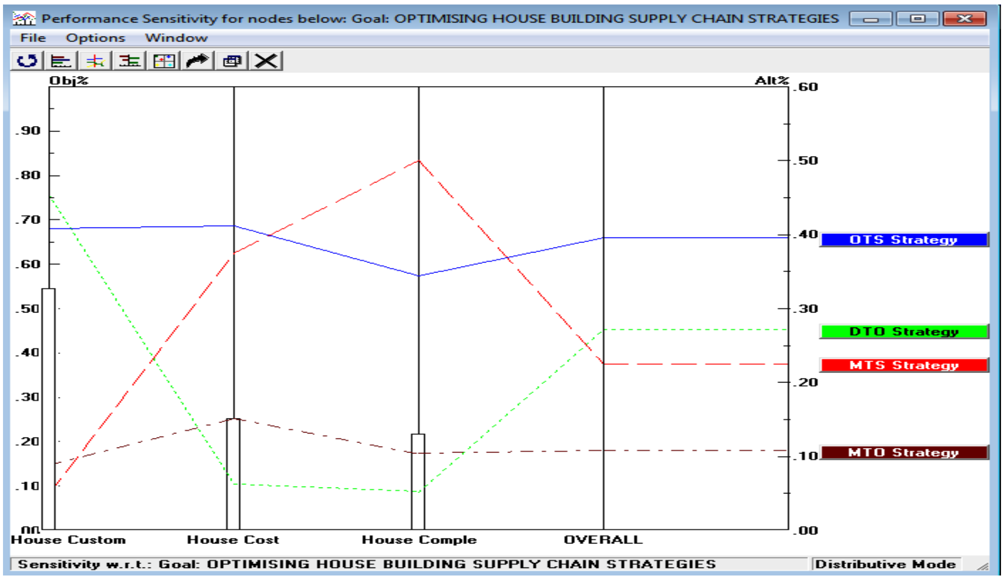

Figure 5: Performance sensitivity graph of house building SC stratgeies.

CONCLUSIONS

Australian house building sector has continuously experienced growing demand in housing. The house customisation and completion time make the design specifications become more complex. Moreover, customer demands are ambiguous and dynamically changed. The leagile SC strategies are suitable to carry out the different finished house demands. The four strategies have been introduced in this paper to fit the different situations of demand and balance the trade-off between house builders and customers. Based on the performance tested using AHP analysis, the last strategy, outsourcing to suppliers, was highlighted as the most suitable for Australian housing constraints. Further research is suggested to investigate into other factors that may strongly influence the housing supply and demand in Australia.

REFERENCES

ABS (2008). Average quarterly completion times for new houses. Building Approvals, Australia. ABS. Canberra, Australian Bureau of Statistics. **8731.0**

ABS (2010). A Statistical overview of the Construction Industry. Australian Economic Indicators. ABS. Canberra, Australian Bureau of Statistics. **1350.0**.

Agarwal, A., R. Shankar and M. K. Tiwari (2006). "Modeling the metrics of lean, agile and leagile supply chain: An ANP-based approach." *European Journal of Operational Research* **173**(1): 211-225.

Bertelsen, S. (2002). Bridging the gap–towards a comprehensive understanding of lean construction. Proceedings of the 10th Annual Conference of the IGLC. Gramado, Brazil.

Chang, A. S. and K. P. Lee (2004). Nature of construction technology. Proceedings of the 12th Annual Conference of the IGLC. Copenhagen, Denmark, IGLC-12**:**74-83.

Chen, I. J. and A. Paulraj (2004). "Towards a theory of supply chain management: the constructs and measurements." *Journal of Operations Management* **22**(2): 119-150.

Chen, Q., G. Reichard and Y. Beliveau (2007). Interface Management—A facilitator of lean construction and Agile Project Management. Procecding of the 15th Annual Conference of the IGLC. Michigan, USA.

Childerhouse, P., S. M. Hong-Minh and M. M. Naim (2000). House building supply chain strategies: selecting the right strategy to meet customer requirements. Proceedings of the 8th Annual conference of the IGLC. Brighton, UK.

Christopher, M. and D. Towill (2001). "An integrated model for the design of agile supply chains." *International Journal of Physical Distribution & Logistics Management* **31**(4): 235-246.

Christopher, M. and D. R. Towill (2000). "Supply chain migration from lean and functional to agile and customised." *Supply Chain Management: An International Journal* **5**(4): 206-213.

COAG (2012). Housing Supply and Affordability Reform. Canberra ACT, Australia, Council of Australian Governements.

Cudney, E. and C. Elrod (2011). "A comparative analysis of integrating lean concepts into supply chain management in manufacturing and service industries." *International Journal of Lean Six Sigma* **2**(1): 5-22.

Dalton, T., P. Chhetri, J. Corcoran, L. Groenhart and R. Horne (2011). "Understanding the patterns, characteristics and trends in the housing sector labour force in Australia." *Australian Housing and Urban Research Institute Positioning* Paper Series(143): 1-88.

Dalton, T., R. Wakefield and R. Horne (2011). Australian suburban house building: industry organisation, practices and constraints. Australian Housing and Urban Research Institute Positioning Paper Series: 1-56.

Daneshgari, P. (2009). Agile Construction : Impact of Project Resource Management on Profits. IEC Insights: 10-12.

Department of Human Services. (2011). "Group Self Build, Housing and Community Building." Housing & Community Building: Finance & Business Services, from <http://www.dhs.vic.gov.au/for-individuals/housing-and-accommodation/home-owner-support/group-self-build>, (12/8/2011).

Gharaie, E. (2011). House Completion Time in Australia: Workflow Planning Approach. Doctor of Philosophy, RMIT University.

Green, S. D., S. Fernie and S. Weller (2005). "Making sense of supply chain management: a comparative study of aerospace and construction." Construction Management and Economics 23(6): 579-593.

HIA (2011). Housing to 2020 : The states of Australian housing to the year 2020. Campbell ACT, Australia, Housing Industry Association Economics Group**:** 33.

Höök, M. and L. Stehn (2008). "Applicability of lean principles and practices in industrialized housing production." *Construction Management and Economics* **26**(10): 1091-1100.

Koskela, L. (1992). Application of the New Production Philosophy to Construction. CIFE, Stanford University, Stanford, CA. **72:** 81.

Lee, S. (2003). Agile Report "The Agile Peformance Improvement Databse: A tool to improve construction performance", School of Management, University of Bath.

Mason-Jones, R. and D. R. Towill (1999). "Total cycle time compression and the agile supply chain." *International Journal of Production Economics* **62**(1): 61-73.

Mossman, A. (2009). "Why isn't the UK construction industry going lean with gusto?" *Lean Construction Journal* **5**(1): 24-36.

Naim, M. and J. Barlow (2003). "An innovative supply chain strategy for customized housing." *Construction Management and Economics* **21**(6): 593-602.

Naim, M., J. Naylor and J. Barlow (1999). Developing lean and agile supply chains in the UK housebuilding industry. Proceedings of the 7th Annual Conference of the IGLC. Berkeley. **7:** 159-170.

Naylor, B. J., M. M. Naim and D. Berry (1999). "Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain." *International Journal of Production Economics* **62**(1–2): 107-118.

NHSC (2012). Housing Supply and Affordability: Key Indicators. A. Government. Canberra ACT, Australia, National Housing Supply Council**:** 64.

Ohno, T. (1988). Toyota production system: beyond large-scale production. *Productivity Press*, Portland, OR.

Owen, R., L. Koskela, G. Henrich and R. Codinhoto (2006). Is agile project management applicable to construction? Proceedings of the 14th Annual Conference of the IGLC. Santiago, Chile**:** 51-66.

Ren, Z., Z. Chen and X. Wang (2011). "Climate change adaptation pathways for Australian residential buildings." *Building and Environment* **46**(11): 2398-2412.

Saaty, T. L. (1980). The analytic hierarchy process : planning, priority setting, resource allocation. *McGraw-Hill International Book Co.*, London

Shah, R., A. Chandrasekaran and K. Linderman (2008). "In pursuit of implementation patterns: the context of Lean and Six Sigma." *International Journal of Production Research* **46**(23): 6679-6699.

Sharifi, H. and Z. Zhang (1999). "A methodology for achieving agility in manufacturing organisations: An introduction." *International Journal of Production Economics* **62**(1): 7-22.

Stock, J. R. and S. L. Boyer (2009). "Developing a consensus definition of supply chain management: a qualitative study." *International Journal of Physical Distribution & Logistics Management* **39**(8): 690-711.

Tam, V. W. Y., C. M. Tam and W. C. Y. Ng (2007). "On prefabrication implementation for different project types and procurement methods in Hong Kong." *Journal of Engineering, Design and Technology* **5**(1): 68-80.

Thorpe, D. and N. Ryan (2007). "Responding to global issues: sustainability and innovation in the Australian SME residential building construction sector." *ICCPM/ICCEM 2007 Proceedings*.

Vrijhoef, R. and L. Koskela (2000). "The four roles of supply chain management in construction." *European Journal of Purchasing & Supply Management* **6**(3–4): 169-178.

Wikner, J. and M. Rudberg (2005). "Integrating production and engineering perspectives on the customer order decoupling point." *International Journal of Operations & Production Management* **25**(7): 623-641.