DECISION SUPPORT MODEL USING ANP TO ALIGN LEAGILE STRATEGIES TO OFF-SITE MANUFACTURING IN AUSTRALIA

Sherif Mostafa
Lecturer, School of Natural and Built Environments
University of South Australia
sherif.mostafa@unisa.edu.au

Tariq Abdelhamid
Associate Professor, School of Planning, Design and Construction,
Michigan State University, East Lansing, MI 48824, USA
tariq@msu.edu

Nicholas Chileshe
Senior Lecturer, Research Education Portfolio Leader,
School of Natural and Built Environments
University of South Australia, City East Campus, Adelaide, SA 5001, Australia
Nicholas.chileshe@unisa.edu.au

Jantanee Dumrak
Lecturer, Global Project Management Program,
Torrens University Australia, Wakefield Campus, Adelaide, SA 5000, Australia
Jantanee.dumrak@tua.edu.au

ABSTRACT

The Australian housing supply has not been adequate to meet the constantly growing demand. Four main factors driving this undersupply in Australian housing are: (1) house completion time; (2) cost of finished house; (3) customer preferences and (4) level of skilled labor. Offsite manufacturing (OSM) could become a key innovation for the future of Australian house building as it provides capacity in meeting the growing housing demand, green construction and lesser requirements for a labor force. OSM is a modern construction method in which house building components are produced in offsite factories and then transported to the construction site to be assembled. The supply responsiveness of OSM can be enhanced by employing lean and agile concepts. In this study, four Leagile strategies are suggested to facilitate house builders decision making based on different combinations of housing supply factors. This paper matches these four strategies with the four studied factors in Australian house building using the Analytical Network Process (ANP). The data employed for the ANP model was derived from the actual specifications of 258 houses built in five Australian states by five major house builders. The results from the ANP model show the suitability in applying each strategy under different degrees influenced by the factors tested.

Keywords: Off-site manufacturing; Australian housing supply; Leagile strategies; ANP

1. Introduction

Residential building is one of the leading sectors in the Australian economy. It consists of many independent building organizations that construct separate houses, semi-detached houses, townhouses, flats, units and apartments (Dowling, 2005). In 2010-2011, the sector reported a significant production value of AUD 47 billion. However, the responsiveness of the values of work commenced in residential building is unlikely to keep pace with the growth of other construction activities (ABS, 2012). This situation is caused by the imbalance of housing supply and demand. Due to the shortage of the housing supply, and neglect of the housing supply challenges, this paper mainly focuses on the Australian housing problems from the supply perspective (COAG, 2012; NHSC, 2013; Liu & London, 2011). This paper addresses four main factors including house construction costs, house completion time, level of skilled labor, and house customer preferences that affect the Australian housing supply. It is evident that more research is required to explore the applicability of Off-Site Manufacturing (OSM) as a new construction method to improve the house building supply in Australia (Blismas & Wakefield, 2009).

In this research, the aim is to enhance the OSM uptake in Australia by integrating lean and agile concepts. Four Leagile strategies are introduced to manage the OSM house building supply chain. The results of this study will answer the research question: “How can house builders select suitable Leagile strategies?” The outcome of the research could lead to the adoption of suitable OSM strategies for Australian house builders.

The cumulative housing supply shortage has been predicted and confirmed by the housing industry alliances such as the National Housing Supply Council (NHSC) and the Housing Industry Association (HIA) (COAG, 2012; Dalton et al., 2011). The housing supply and affordability report produced by NHSC (2013) projects the gaps between the underlying demand and supply in housing from all scenarios between June 2011 and June 2031. In a low build rate situation the difference between demand and supply is forecasted to reach 415,000, 943,000 and 1,558,000 dwellings in low, medium, and high demand growth, respectively. For the high demand growth, the expected shortage of dwellings will be 1,558,000, 1,050,000, and 447,000 dwellings, respectively.

It is predicted that the practice of OSM will gradually play a major part in Australian house building in the coming decades (Blismas & Wakefield, 2009; Hampson & Brandon, 2004). The opportunities to adopt OSM in Australia are centered on detached houses, high-density multi-residential complexes, and public facilities such as hospitals and schools. The development of OSM will expand to walling systems, modularized housing and light weight concrete wall panels. Despite the potential of OSM in Australia, the uptake of OSM has been limited due to some barriers such as the builders conservatism influenced by the limited success in the past, high fragmentation in the construction industry, a lack of codes and standards, loss of control on-site and into the supply chain, lack of skilled labors, and insufficient industry investment in research and development. Employing some concepts such as lean and agile manufacturing could contribute to the success of enhancing OSM uptake in the house building industry (Manley et al., 2009). Four different leagile strategies introduced in this paper are Make-To-Stock (MTS), Assemble-To-Order (ATO), Design-To-Order (DTO) and Self-Build-House (SBH). Using the Analytic Network Process (ANP) will enable house builders to select the most appropriate strategy that fits their supply conditions.

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

This paper is organised into eight consecutive sections. After the introduction, the second section demonstrates the research aim and objectives. The third section reviews the related literature on Australian housing supply factors, OSM, and lean and agile concepts. Section four explains the four leagile strategies for OSM and the related case studies. The fifth section summarises the research methodology. The sixth section introduces the proposed ANP model which is applied to study the four leagile strategies. The seventh section discloses the results delivered by the ANP model based on the data of 258 houses built in five Australian States including Western Australia (WA), South Australia (SA), New South Wales (NSW), Victoria (VIC), and Queensland (QLD). In the final section, the research conclusion provides recommendations for further research.

2. Research aim and objectives

The aim of this study is to introduce OSM house building supply strategies to Australian house builders. To achieve this, four research objectives have been developed:

1) Highlight the factors contributing to Australian housing supply.
2) Discuss the potential of OSM in Australia.
3) Present an integrative framework of lean and agile in OSM supply chain.
4) Develop a decision support model using ANP for leagile strategies selection in order to enhance the OSM adoption in Australia.

3. Literature review

3.1 Factors influencing Australian housing supply

The housing supply in Australia is comprised of several stages which can influence the housing supply and demand such as strategic planning and development, land release, building approval, construction commencement and completion, strata title registration and availability for occupation (NHSC, 2013). The main focus of this paper is on the house construction process which starts from the commencement of house building and concludes with house completion as the latest statistics of ABS (2014) indicated that the number of houses completed is lower than the number of houses commenced. Therefore, identifying the factors affecting the house supply that exist in the construction process of the house is a crucial step in achieving the aim of this paper. The main factors discussed are as follows: completion time for new houses, house customer preferences, level of skilled labor and house construction costs.

3.1.1 Completion time for new houses

The house completion time is the time period between the first and last physical building activity to make a house ready for occupation (Dalton et al., 2013). 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 been found to be relatively stable. The statistics of ABS (2014) reported the average completion times of new houses in Australian states, territories, and at the 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 an 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 increased in all regions in 2003 to 2008. The states of Western Australia and Victoria were recorded as having the longest house completion time at approximately 3.3

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

quarters in 2013. The house completion time in the states of NSW, SA and TAS is around 2.8 quarters. At the national level, the completion time has been increased from two quarters in 2005 to be three quarters in 2013.

3.1.2 House customer preferences

The house type and design are the main factors in a house buyer's preference (NHSC, 2013). House preferences may vary from person to person based on, but not limited to, household age and income, and family size. House preferences include the size, internal and external design, and location of the house. The average floor area Australian dwelling has increased over time. For example, the average floor area of new detached houses increased from 162.4 m^2 to 248.0 m^2 from 1984 to 2009 (ABS, 2012). It is evident from an examination of volume builders catalogues such as Metricon, one of the largest 20 home builders in Australia, that the building of double-story houses and more complex street-facing façades has increased (HIA 2013).

3.1.3 Level of skilled labor

House building is a labor intensive industry with its main product being new dwellings or renovated dwellings. The supply of labor is an important element of the housing supply. According to DEEWR (2012), shortages reported from 2008 to 2012 in some construction trades were roof tiller, glazier, plumbers and cabinetmakers. House builders are working in a competitive environment in which skilled labor is required. The challenges in house building include new working relationships such as partnering and virtual enterprise as well as changing construction technologies and adopting modern methods of construction (Daly, 2009). It can be concluded that skilled labor is an essential component of the house building industry in order to successfully overcome all the mentioned challenges. On the other hand a skills shortage contributes to the undersupply of housing (NHSC, 2013).

3.1.4 House construction costs

Housing prices are a critical element in determining new housing construction. In Australia, house prices have increased in all locations at a similar rate of growth. The ABS (2014) reported that the Houses Price Index (HPI) for the weighted average of the eight capital cities increased by 3.4% during the December 2013 quarter. This led 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 the house price. The house price is comprised of the price of land, construction costs, and lagged house stock. The growth of house prices is driven by the increase in the prices of established 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. This study concluded that the construction costs are a significant component of the poor performance of the Australian new housing supply.

3.2 Off-site manufacturing in Australia

In order to respond to the housing shortage, builders are looking for more efficient materials and new methods of construction that can reduce the completion time. One example of a new material is the use of Cross-Laminated Timber (CLT) instead of traditional clay bricks. A new method in house building is employing Off-site 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 a cleaner and tidier construction site as well as enhancing quality of the house components under

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

controlled factory production. Furthermore, OSM reduces environmental effects by reducing waste generation, shortening lead time and increasing efficiency and productivity (Pan & Goodier, 2012). There are four categories of OSM based on the degree of offsite work. These categories are: component manufacture and sub-assembly which are always made in a factory and never considered for onsite construction (e.g. door, trusses, windows); non-volumetric pre-assembly (panels) which are pre-assembled units which do not enclose usable space (e.g. wooden panels and Structural Insulated Panels); 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 modular systems which are pre-assembled volumetric units which also form the actual structure and fabric.

Previous studies have positively addressed OSM in the Australian built environment. Hampson and Brandon (2004) identified OSM as a key vision for improving the construction industry by 2020. Manley et al. (2009) confirmed that OSM has the capability to produce high-volume and high-quality houses based on the efficiencies of the manufacturing principles. Likewise, Khalfan and Maqsood (2014) recommended adopting OSM in the Australian residential sector for enhancing house affordability, reducing construction time and improving quality. Chandler (2014) contended that the underperformance of the Australian construction industry could be improved through including the adaption of OSM. He also mentioned that there could be an increase in the employment of OSM by 2023, which could be achieved through sourcing 15-20% of the total industry turnover offshore. Despite the benefits of OSM, the uptake in Australia is limited due to some challenges which are similar to those in different contexts (Blismas & Wakefield, 2009).

Some major challenges are related to concurrent management of two working sites (Chang & Lee, 2004). These challenges include the potential of insufficient coordination between the offsite and onsite activities, the jumbled on-site processes due to a difference between the production flow at offsite factories and construction flow on-site, and the vague demands from undecided customers. In addition, Khalfan and Maqsood (2014) highlighted some challenges related to the industry such as the lack of skilled Australian supply chain partners and the lack of scale in the residential sector. The non-value added activities (wastes) in the production of house components/modules present further challenges. All of these challenges might lead to a slower response to customer order completion. Addressing these challenges has typically followed the implementation of successful concepts from the manufacturing industry, particularly lean and agile concepts (Blismas, 2007; MHRA, 2003; Vidalakis et al., 2013).

3.3 Lean and agile concepts in OSM

3.3.1 Lean concept

Lean Manufacturing was first developed as part of the Toyota Production System (TPS) and later expanded to be known as Lean Production. Lean is an integrated socio-technical system comprised of management practices that focus on eliminating waste from business and production processes so that the time between the customer order and actual product delivery is reduced to the shortest possible time (Shahet al., 2008). This is a time to market focused strategy. Lean thinking contains five general principles including defining value from the customer perspective, mapping the value stream to achieve the predefined value, creating the flow along the value stream, establishing pull systems and pursuing perfection (Womack & Jones, 2003). The lean

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

principles are applied through using a set of tools to identify and eliminate waste in the value stream (Mostafa et al., 2013).

The lean tools include just-in-time (JIT), batch reduction, facility layout, value stream mapping (VSM), visual management system, production levelling, pull production system, total productive maintenance (TPM), quick changeover, standard work, error proofing, Kanban, and Kaizen (Shah & Ward, 2003). Lean thinking as an application into the construction environment was first discussed by Koskela in 1992 (Mossman, 2009). A transformation-flow-value concept of production has been developed as a new perspective to improve facility construction performance (Koskela, 1992a). According to the 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; Abdelhamid, 2004; Pasquire, 2012a).

3.3.2 Agile concept

The agile manufacturing concept, on the other hand, became popular in 1991. Sharifi and Zhang (1999) stated that a new competitive environment is a key driver for changes in the manufacturing industry. The competition qualities are continuous improvement, rapid response and quality improvement. The researchers at the Iacocca Institute in Lehigh University (USA) defined the agile concept (Yusuf et al., 1999) as:

> A manufacturing system with extraordinary capabilities (Internal capabilities: hard and soft technologies, human resources, educated management, information) to meet the rapidly changing needs of the marketplace (speed, flexibility, customers, competitors, suppliers, infrastructure, responsiveness). A system that shifts quickly (speed and responsiveness) among product models or between product lines (flexibility), ideally in real-time responding to customer demand (customer needs and wants).

The agile principles include organizing in order to master change and uncertainty, leveraging the impact of people and information, cooperating to enhance competitiveness and enriching the customer (DeVor et al., 1997; Gunasekaran et al., 2002). The agile concept has three dimensions: drivers, enablers and capabilities as demonstrated in Figure 1. The figure is inspired by the work of Sharifi and Zhang (1999) for the concept of agility drivers interacting with the agility enablers to deliver agility capabilities. However, the projected figure contains drivers and enablers proposed in other research. The agility drivers have been identified in Zhang and Sharifi (2007) whilst the four categories of agility enablers have been highlighted and discussed in Yusuf et al. (1999), Gunasekaran et al. (2002) and Sharp et al. (1999).

Vol. 7 Issue 3 2015
ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

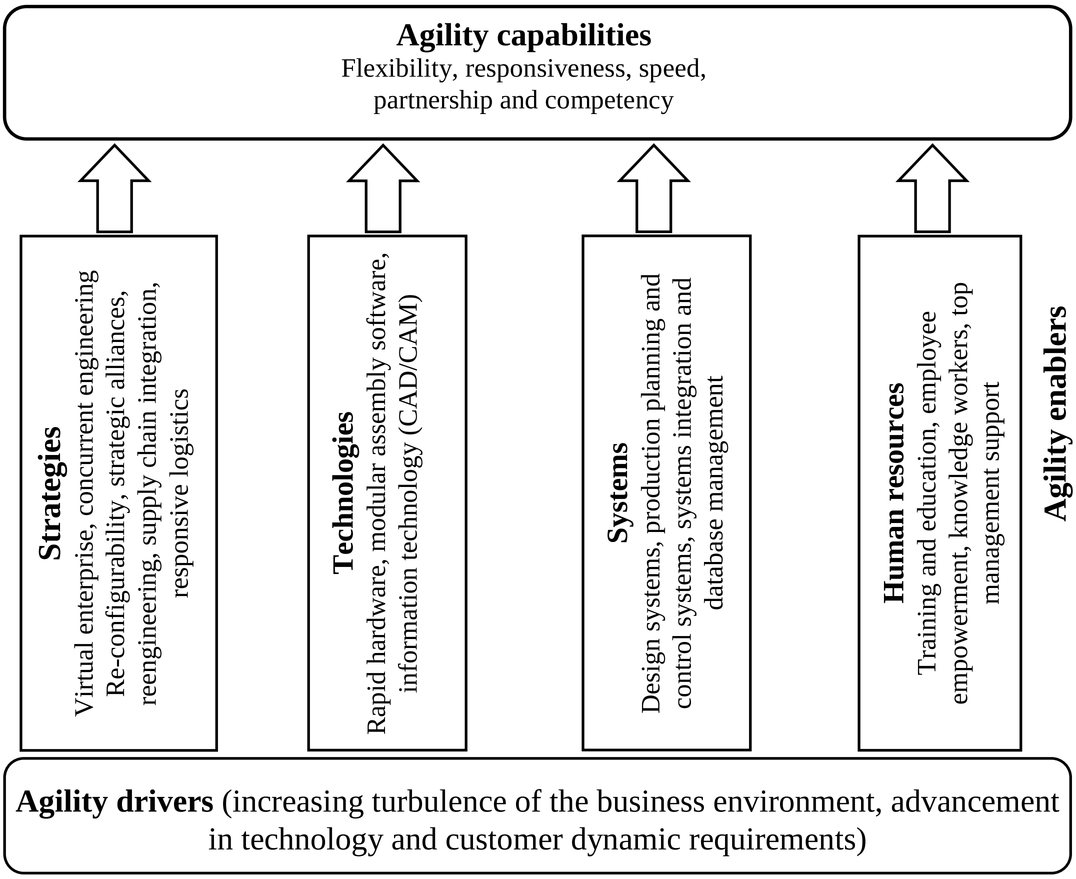


Figure 1. Agile concept drivers, enablers and capabilities

The key drivers of adopting the agile concept are increasing turbulence of the business environment, changes in customer requirement and advancement in technology. The agile capabilities refer to the capabilities that an organization needs to attain to be able to respond to the agility drivers. The capabilities are flexibility, responsiveness, speed, partnership and competency (Zhang & Sharifi, 2007). Agility enablers consist of business practices, methods and tools which enable an organisation to acquire the agile capabilities (Sharifi & Zhang, 1999). The tools/practices are grouped into four areas: strategies, technologies, systems and human resources. The initiative of agile construction was established in direct response to the *Latham Report* published in 1994 (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 entire industry needed to change. Benchmarking has been a method used to stimulate the required change in the construction practices. Naim et al. (1999) suggested the employment of agile principles in the construction supply chains to achieve profitable opportunities in dynamic markets. Agile construction exemplifies the characteristics of visibility, responsiveness, productivity and profitability (Daneshgari, 2010).

3.3.3 Leagile concept

The integration of lean and agile is one of the better solutions to answer any changes in the world class market competition (Agarwal et al., 2006). Combining lean and agile within the whole supply chain can be accomplished by using the decoupling point (DP) concept. It is known as leagility. The leagility term was first introduced by Naylor et al. (1999). In general, the DP separates the leagile supply chain into lean in the upstream and agile in the downstream (Mason-Jones & Towill, 1999). For market

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

competition, Christopher and Towill (2000) emphasised that supply chains must be responsive to market demand changes which can be divided into three critical dimensions; variety, variability (or predictability) and volume.

The lean concept is the better alternative where there are high volumes, low variety, and low predictable change environments. Conversely, the agile concept is the better option where there are low volumes, high variety, and high predictable change environments. The real demand visibility is limited in most supply chains. The supply chains may be lean prior to DP and agile beyond DP. There are two DPs in the leagile supply chains (Christopher & Towill, 2000). The first DP is the material DP which should ideally lie as far down stream as possible to be close to the final marketplace. The second DP is the information DP which should lie as far upstream as possible in the supply chain. Agility beyond the decoupling point is explained by the principle of postponement using a generic or modular inventory to postpone the final commitment while the final assembly or customisation depends on real demand.

A leagile supply chain has capabilities to achieve value through different strategies in accordance with the DP positions for the house customer. The leagile house building supply chain mainly focuses on waste removal and responsive mechanisms through applying the excellent practices lean and agile have to offer. The studies of Childerhouse et al. (2000) and Naim and Barlow (2003) focus on using the material DP in the UK house building supply chain. In this paper, the leagile house building supply chain employs the customer order decoupling point (CODP) or order penetration point which encompasses both information and materials. 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.

3.3.4 Application of lean and agile in OSM

Lean concept is comprised of management practices that focus on eliminating all forms of waste from the value stream (Sertyesilisik, 2014). The concept has been widely adopted beyond its origin in automobile manufacturing. Kenley (2014) emphasized improving the productivity of the construction industry through production systems intervention. Lean production concept is the best known intervention. It has been used by house manufacturers in Japan by transferring the knowledge from automobile manufacturing to house manufacturing (Barlow & Ozaki, 2005).

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, as extended by Koskela (1992b), addresses these specific characteristics. The main challenge of Lean Construction is related to the interfaces between the offsite factory 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 to proactively respond to any onsite uncertainties (Daneshgari, 2010). Lean construction focuses on creating an efficient physical process of manufacturing (Pasquire, 2012b). Agile, on the other hand, emphasizes a high level of service through flexibility and customization (Naim & Barlow, 2003). These factors are important for OSM as OSM implies standardization of products and processes, and emphasizes flexibility for house customers.

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

Some concerns were found in the existing literature in applying lean or agile as a standalone concept when uncertainties in construction are present (Christopher & Towill, 2001). Many studies suggested a combination of lean and agile concepts in OSM (Blismas & Wakefield, 2009; MHRA, 2003). However, these studies were conducted in a different context than the Australian house building environment. It was further discovered 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 strategy known as leagile (Purvis, Gosling, & Naim, 2014). In general, the decoupling point separates the supply chain into lean in the factory site and agile in the construction site.

3.3.5 Current gap of knowledge on lean and agile concepts in OSM

The principles of lean and agile are easily extended to different types of organizations (Womack & Jones, 2003). They can be combined appropriately within designed and operated total supply chains via decoupling points (Agarwal et al., 2007). Nevertheless, research efforts focused on the shortcomings as well as strengths of such a combination has been inadequate. Combining lean and agile practices without a full understanding of their power and limitations may result in major errors. The definition of waste in agile is different from that appropriate to lean therefore, whatever is considered waste in a lean concept may be an essential practice in agile concept (Towill & Christopher, 2002). Capacity requirements are one example of this difference according to Mason-Jones, Naylor, & Towill (2000). According to lean concept, unnecessary inventory is waste however; from an agile point of view it is recommended that certain levels of inventory should be sustained to handle unpredictable demands.

In the house building sector, synergizing lean and agile concepts may require more examination into their effects on reducing house completion time and construction costs overrun. OSM consists of several interrelated sub-areas needed in delivering houses according to customer demands. Table 1 presents a summary of the existing literature on the manufacturing application concepts suggested for house building. Among the five major countries which are frequently included in house building studies, lean and agile are suggested the most. Nevertheless, the integration of these two principles seems insufficient. Naim and Barlow (2003) suggested leagile supply chain strategies for the UK house building. The strategies are based on using a material decoupling point to separate lean and agile. However, their study has not demonstrated the CODP which is regarded as a significant component for the house customers' preferences and has excluded the practices of lean and agile required for house building supply chain.

The literature in the Australian context on lean and agile applications of OSM reveals a shortage of lean and agile implementation in the house building sector. The development of OSM in house building, to some extent, lacks a clear description of the concept and its related parts, including technical, organizational and process-related issues. In order to achieve an effective building process, OSM must be based on a holistic view (supply chain view). However, this can lead to consequences for the structure of the building process in terms of changes of organizational and production related conditions. The general house building process is not designed to handle the whole process as a supply chain. Hence, it may require changes to both the process and the management to get the OSM system to work effectively with its related parts acting together as a whole and creating maximal value for the customers (Lessing,2006).

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

Table 1
Literature review of the manufacturing application concepts suggested for house building

Countries	Research studies	Lean	Agile	Leagile
U.K.	Re-engineering through pre-assembly (Gibb & Isack, 2003)	*		
	Innovative supply chain for customised housing (Naim and Barlow, 2003)	**	**	**
	Delivering new homes-the offsite way (Arif & Pannell, 2013)	*		
	Offsite production a model for building down barriers (Nadim & Goulding, 2011)		*	
U.S.	Current Use of Offsite Construction Techniques (Na Lu & Liska, 2008)	*		
	Designers' and General Contractors' Perceptions of Offsite Construction Techniques (N. Lu, 2009)	*		
	Whole house and building process redesign (PATH, 2002)	*	*	
	Technology roadmap for manufactured housing (MHRA, 2003)	*		
Australia	Construction 2020 (Hampson & Brandon, 2004)			
	OSM in Australia current state and future direction (Blismas, 2007)	*		
	Organizational change in Australian building and construction (McGrath-Champ & Rosewarne, 2009)	*		
	Drivers and constraints of OSM (Blismas and Wakefield, 2009)	*		
	Innovative practices in the Australian built environment (Manley, Mckell, & Rose, 2009)	*	*	
Japan	Building mass customised housing (Barlow and Ozaki, 2005)	*	*	
	Choice and delivery in house building (Barlow et al., 2003)	*	*	
	Similarities and differences between industrialized housing and car production in Japan (Gann, 1996)	*		
Sweden	Industrialised house building (Lessing, 2006)	*	*	
	Applicability of lean principles and practices (Höök & Stehn, 2008)	**		
	Defects in offsite construction (Johnsson & Meiling, 2009)	*		
	Value-driven purchasing of kitchen cabinets in industrialised housing (Bildsten, Björnfot, & Sandberg, 2011)	*		

**: Application suggested and applied within the study *: Application suggested but not applied within the study

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

4. Leagile strategies for OSM supply chain

The OSM house building supply chain suggested in this paper can be visualized as shown in Figure 2. The supply chain is comprised of the house materials suppliers, an offsite factory, designers, construction site, and customers. The OSM supply chain must be managed to achieve the customer order. 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 organization management and the field persons. The LPS facilitates the workflow so that labor and material resources can be more productive. The LPS encompasses four levels of planning processes with different consecutive spans: master scheduling, phase scheduling, make-ready planning, and weekly work planning (Forbes & Ahmed, 2011).

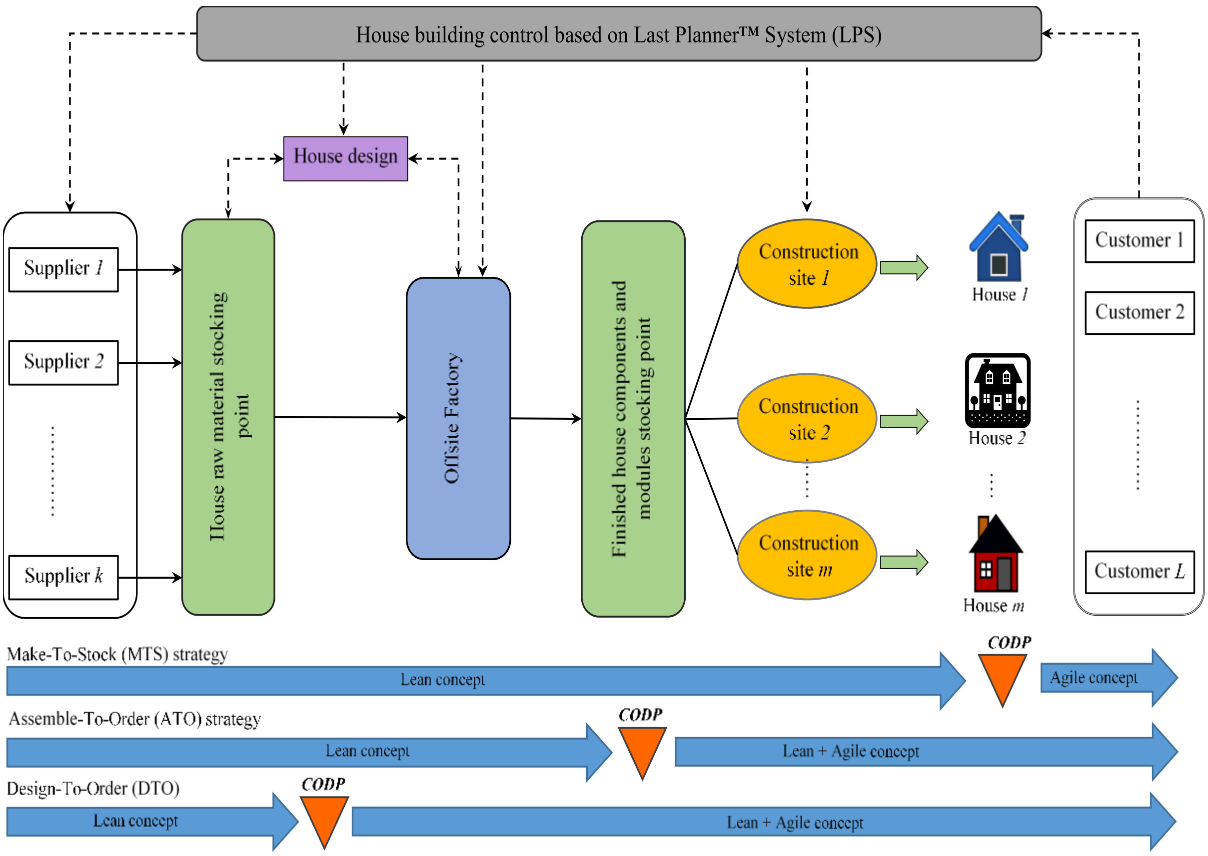


Figure 2. OSM supply chain and included Leagile strategies

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 organizations to find the best way to meet milestones stated in the master schedule. The make-ready (look-ahead) planning 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). The weekly work planning represents the most detailed plan in the LPS showing interdependence between the works of various specialist organizations and 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.

The previous research of Childerhouse et al. (2000), and Naim and Barlow (2003) 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 CODP which was suggested by Olhager (2013). 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 the Australian house building supply chain. These strategies are summarized in Table 2.

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

Table 2
Leagile strategies for OSM supply chain

Strategy	Description	CODP Location	Leagile	Attractiveness to Customers	Benefits to Builders
Make-To-Stock (MTS)	• Known as speculative house • Houses are designed and built based on the builders' catalogue	After the onsite construction activities and finished house building	• Lean is for cost-related activities before selling • Agile is after house construction to reduce the delivery time	Lower price of a finished house	• Maximization on house price satisfaction • Speed up the return on investment
Assemble-To-Order (ATO)	A variety of houses designs are available to the customers in the catalogues	At the offsite factory	• Lean is employed within the offsite factories • Agile is employed in stages of shipments and onsite construction	• A degree of flexibility in selecting house components • Available of mixed 'specs' to match demands • Price of house modules and faster completion time	More customer satisfaction
Design-To-Order (DTO)	The house design can be delivered to the customers who prefer to have their own house modules	House design stage	• Lean is applied in supplying material and offsite operations • Agile is applied for high responsiveness of other activities	• More control over house preferences • Flexibility to change the predesigned modules	More customer satisfaction
Self-Built House (SBH)	The house owner is involved in every house building process. The house owners are at their own responsibilities to hire builders to assist them with some onsite construction activities.	At house components suppliers	• Lean is suitable to run the factory to produce house modules, • Agile is the best option for quick responses to demands of self-build house suppliers.	• Various designs • Attractive price • High customization • Full control over the construction process	• Opportunities as suppliers • Simple designs required • Meet different demands • Standard components

5. Research methodology

To achieve the aim of this paper, an exploration of various databases obtained from Australian housing bodies, i.e., National Housing Supply Council (NHSC), Housing Industry Association (HIA), Australian Bureau of Statistics (ABS), Australian Housing and Urban Research Institute (AHURI), and Council of Australian Governments (COAG) was employed. This database exploration was divided into two stages: constructing a background of OSM builders in Australia and identifying factors related to the four leagile strategies that could indicate OSM uptake in Australia. The data sets obtained from these stages were utilized in formulating decision making of OSM strategy among the proposed strategies for the Australian context. The collected data were examined and allocated reference numbers to facilitate the data analysis process. The process of decision making formulation was conducted using the Analytic Network Process (ANP). The exploration process resulted in data from 258 houses built in five Australian States by five volume builders to be analyzed further by ANP.

6. Data Analysis

6.1 OSM builders in Australia

The Housing 100 Report for 2013 presented Australia's most active 100 builders (HIA, 2013). Their main housing activities contributed around 75% of the housing supply for detached houses and multi-unit apartments. In this paper, the top five potential builders supplying houses in the five Australian States of Western Australia (WA), South Australia (SA), New South Wales (NSW), Victoria (VIC), and Queensland (QLD) were analyzed as shown in Table 3. The five builders were capable of adopting the four Leagile strategies. This adoption capacity was enhanced by their house building work in the five states, market share, decision making and the future trends during the period of 2011-2014 (HIA, 2014). The strategies would allow builders to make decisions to tailor their house building activities. The weightings of the criteria and sub-criteria for each strategy were grounded on the specifications of 258 actual houses. The specifications obtained were classified into groups under each criterion and sub-criterion before pairwise comparisons were conducted to predict the most suitable strategy.

Table 3
Top five Australian house builders' information 2013/2014

	Builder A	Builder B	Builder C	Builder D	Builder E
HIA top 100 2013/2014	1st	2nd	3rd	4th	5th
States of Australia	WA	WA,VIC	SA, VIC, NSW, QLD	QLD,VIC, SA	VIC, SA, QLD
House building activity	Builder	Builder and developer	builder	Builder and developer	Builder
Houses starts during 2013	3443	3199	2837	2432	1692
House market share	13%	12%	10.7%	9.2%	6.4%
Number of house models	224	102	60	56	36

6.2 Leagile strategies' weighting in each criterion and sub-criteria

The imbalance between the housing supply and demand has occurred in all Australian states and territories (NHSC, 2013). The five selected potential builders were capable of adopting the four Leagile strategies. This adoption capacity was enhanced by their house building work in the five states, market share, decision making and the future trends during the period of 2011-2013 (HIA, 2013). Selecting a strategy depends on the situation of the house market in Australia, given that the demand of house customers' shapes the housing market. Therefore, the builders can respond to house market changes by adopting the suitable strategy. For example, the builders might have to build small floor plan houses, less customized with a medium price for the Australian low income groups (to increase housing affordability). This combination could lead to the employment of one or more strategies proposed in this paper. The Australian medium income groups might prefer to select house elements and design from the available designs in the builders' catalogues. In this case, a suitable

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

strategy for this situation must be carefully determined. The customers have the ability to change the house design to fit their needs. Therefore, customers are likely to be involved in designing all house elements. Therefore, the four strategies proposed can cover different customers' demands. The strategies allow house builders to make decisions to tailor their house building activities. The weightings of the criteria and sub-criteria for each strategy were performed through a comparison when a builder employs each strategy. The weighting criteria and sub-criteria for the four strategies are demonstrated in Table 4.

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

Table 4
Leagile strategies' weighting in each criterion and sub-criteria

		A1: ATO	A2: DTO	A3: MTS	A4: SBH
C1: House price		Moderate range	High range	Low price range	Low-Moderate range
C1.1:	Labor cost	Medium	High	Low	low
C1.2:	Construction material cost	Medium	High	Low	low
C2: House completion time		Moderate	Long	Short	Moderate-Short
C2.1:	Construction method	Favorable	Neutral	Favorable	Very favorable
C2.2:	Number of houses under construction	Moderate	Many	Few	Few
C3: House preferences		Moderate	Very High	Low	High
C3.1:	Façade options	Medium	Very high	Limited	Moderate-High
C3.2:	House floor area	Small floor area	Larger floor area	Small floor area	Suitable for any floor area
C3.3:	House location	Flexible location	More flexible	Fixed location	Highly flexible
C4:Level of skilled labor		Medium to high labor intensive	Medium to high labor intensive	Medium	Low
C4.1:	Contractors/sub-contractors	Medium to high contractors	Medium to high contractors	Medium contractors intensive	Requires less contractors force
C4.2:	Trades	Medium to high trades	Medium to high trades	Medium labor intensive	Requires less labor force

6.3 ANP Model

ANP is a technique in multi-criteria decision analysis (MCDA) based on relative assessment of both tangible and intangible criteria (Ozdemir, 2005). It is considered an expansion of the AHP for representing and analyzing a network of decision making. ANP is an easy technique to apply, and allows for a direct calculation of the combined effects of all the factors, utilizing a Markovian process and a more complete set of relationships that are allowed to flow through the network (Saaty & Shang, 2007). ANP can be incorporated with other optimization approaches such as fuzzy and multi objective optimization (Saaty & Sodenkamp, 2008; Bijan, Keramati, & Salehi, 2014). Its pairwise comparisons between the network elements are completed using a decomposition approach that reduces the decision-making errors (Ozdemir, 2005). Applying ANP reduces the rank-reversal problem (Sarkis, 2003). According to the advantages stated, ANP is employed in this study for facilitating the selection of four Leagile house building strategies with respect to the key factors affecting the housing supply in Australia. The simple network model for associating the main house undersupply factors and Leagile strategies is demonstrated in Figure 3.

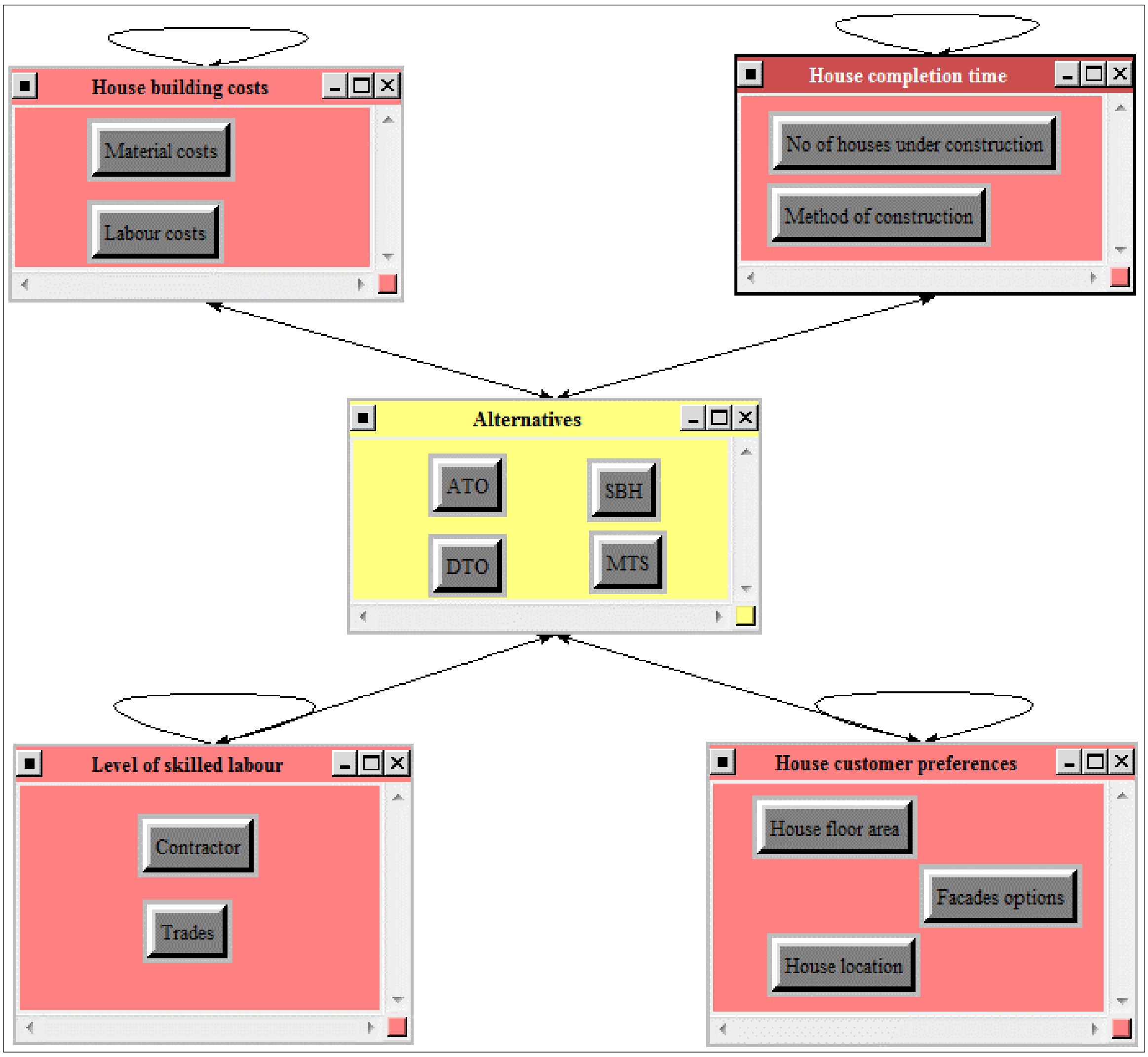


Figure 3. ANP model to align Leagile strategies with house supply factors in Australia

The model contains five clusters. The first cluster represents the house completion time factor. Under house completion time, there are two nodes namely number of houses under construction (NHUC) and house construction method. The house building costs cluster includes material and labor costs nodes. The third cluster is the level of skilled labor which includes contractors and trade persons. The house customer preferences cluster contains three nodes of house floor area, house location and façade options. The last cluster represents the alternatives which are the four Leagile strategies. The model network, comparisons and assessments among the clusters and nodes were created and performed using Super Decisions Software.

The graph of the dependencies among the decision model criteria is demonstrated in Figure 4. The codes of the criteria used in the figure are demonstrated in Table 4. The adjacency matrix can be obtained for the binary relation showed in Figure 4. The matrix shows the contextual relationship among the criteria/clusters of the decision model. The matrix elements are wither 1 or 0, respectively, whether a pair of nodes is directly connected or not.

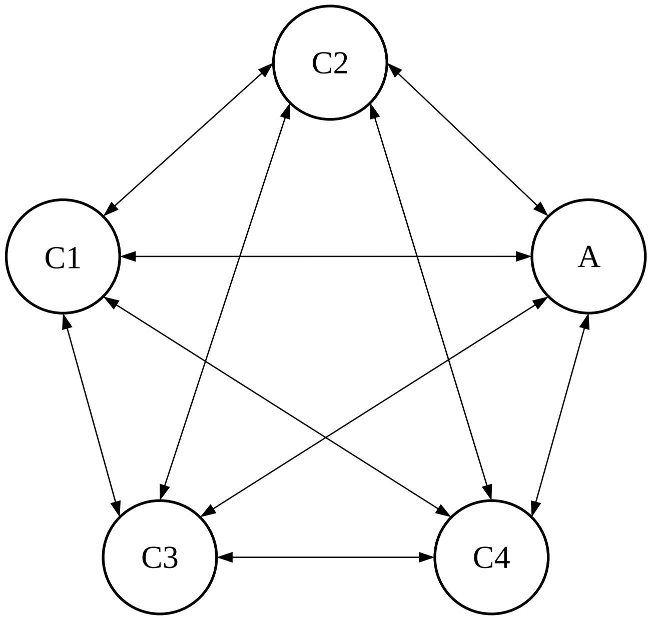


Figure 4. The dependencies among the criteria of the decision model

$$
\text{Adjacency matrix} = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ A \end{array}
\begin{array}{c}
\begin{array}{ccccc} C_1 & C_2 & C_3 & C_4 & A \end{array} \\
\begin{bmatrix} 00 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 1 & 0 \end{bmatrix}
\end{array}
$$

6.4 Pairwise comparisons

ANP can be applied by using Super Decisions© software to ease mathematical calculations. The software has advantages including a user friendly environment, an evaluation of inconsistency index of assessments, and a sensitivity analysis of results. Pairwise comparisons were performed to associate the relationships between all elements at all levels of the ANP network. All pairwise numerical comparisons were performed in the Super Decisions software.

Saaty's 1-9 scale allows the comparison of two elements in the hierarchy using verbal or numerical judgments as equally (i.e., has a value of 1), moderately (i.e., has a value of 3), strongly (i.e., has a value of 5), very strong (i.e., has a value of 7), and extremely (i.e., has a value of 9). The intermediate values are used where appropriate as equally to moderately (i.e., has a value of 2), moderately to strongly (i.e., has a value of 4), strongly to very strongly (i.e., has a value of 6), very strongly to extremely (i.e., has a value of 8) (Armacost, Componation, et al., 1994; Saaty, 1980).

6.4.1 Cluster comparisons

The ANP model clusters are compared with respect to each other in order to evaluate the priorities. Then the priorities are used to weight the blocks in each column of the Supermatrix to make its column stochastic (Saaty & Sodenkamp, 2008). The Cluster matrix is presented in Table 5.

Table 5
Cluster matrix weight

	Alternatives	C1	C2	C3	C4
Alternatives	0.00	0.50	0.50	0.50	0.50
C1	0.18	0.00	0.00	0.00	0.00
C2	0.28	0.00	0.50	0.00	0.00
C3	0.24	0.00	0.00	0.50	0.00
C4	0.3	0.00	0.00	0.00	0.50

6.4.2 Comparisons of elements and alternatives

The Unweighted Supermatrix is constructed from the priorities derived from the different pairwise comparisons (Saaty & Sodenkamp, 2008). The matrix rows and columns contain the cluster nodes labels which are the alternatives and criteria (shown in Table 5). The column of priorities for a node at the top of the Supermatrix includes the priorities of the nodes on the left side of the matrix that have been compared with respect to Leagile strategies on that node. The summation of these priorities is equal to one. The weights derived from the Unweighted Supermatrix (Appendix A) are used to develop the columns in the weighted Supermatrix (Appendix B). Each column is a normalized eigenvector of the Unweighted Supermatrix with some zero records (Bijan et al., 2014). Then, the Unweighted Supermatrix is multiplied by the cluster priority weights (Appendix A). Finally, the limit Supermatrix has been developed using the same process as in the weighted Supermatrix. As shown in Appendix C, all the columns of the limit Supermatrix are identical.

6.5 Final priorities

After pairwise comparisons, the priorities were synthesized from the goal while the overall priorities were calculated. The overall priorities of the ANP model elements are displayed in Appendix C. The SBH strategy was considered as the best alternative which received the highest rating of 0.163. The second best strategy was MTS which scored 0.092, followed by ATO with a score 0.070. The last strategy was DTO with a score of 0.069. The priorities of the other factor in the cluster of the housing supply factors were also provided in Table 6. The NHUC was considered as the most effective factor among other factors. The NHUC scored 0.124. The shortage of trades and labor costs come as the second and the third most effective factors with a score of 0.118 and 0.071.

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

Table 6
Final priorities of the elements of the ANP model

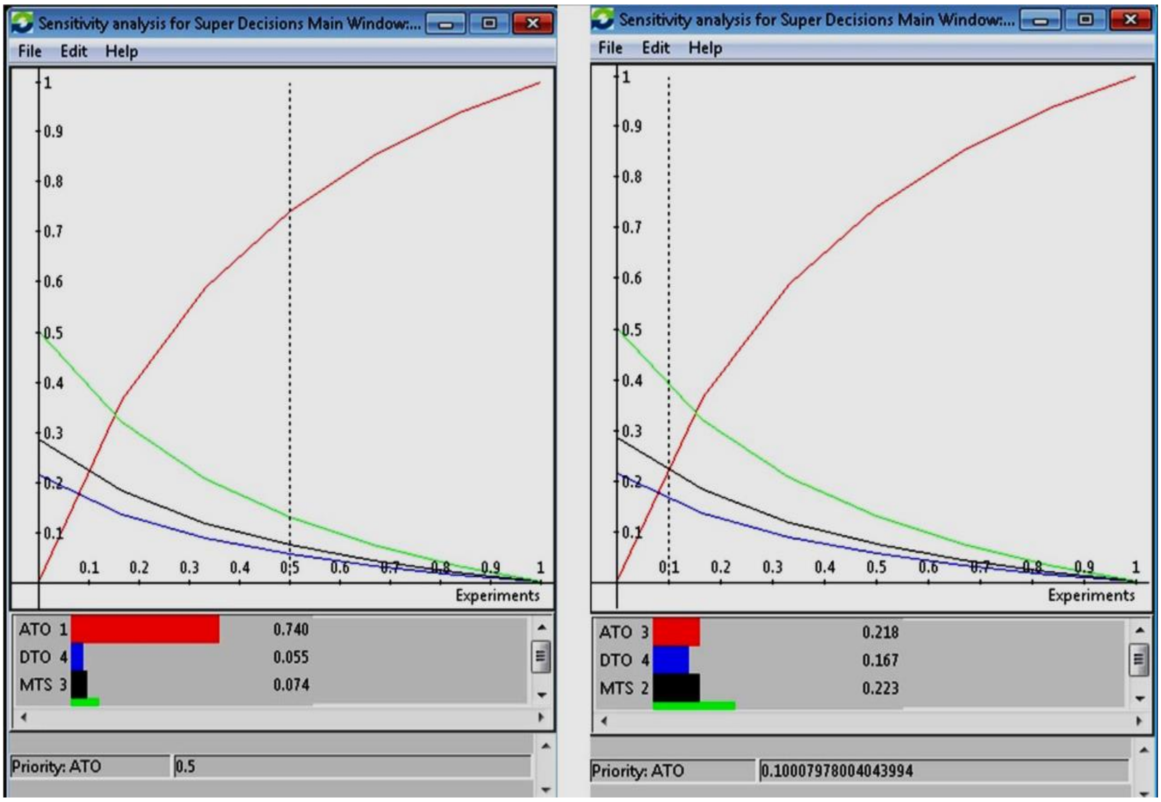
Element	Name	Priority vector
A4	SBH	0.163
C2.2	NHUC	0.124
C4.2	Trades	0.118
A3	MTS	0.092
C1.1	Labor cost	0.071
A1	ATO	0.070
C4.1	Contractors/sub-contractors	0.070
A2	DTO	0.069
C3.3	House location	0.054
C3.1	Façade options	0.050
C3.2	House floor area	0.040
C1.2	Material costs	0.038
C2.1	Method of construction	0.034

7. Results and discussion

7.1 Sensitivity analysis

A sensitivity analysis is conducted in order to determine the stability of the preference ranking among the alternative websites by changing the priority weights of the criteria. If the ranking does not change, the results are said to be robust. In this study, sensitivity is performed by varying the priority of the reliability of ATO strategy by moving the vertical line and determining the corresponding alternatives priorities. Figure 5a shows the graphical representation of the sensitivity analysis when the priority of ATO strategy is 0.5. The rating of the alternatives is ATO, SBH, MTS, and DTO respectively. When the priority of the ATO is reduced to 0.1 (shown in Fig. 5b), the rating of the alternatives has changed. The SBH strategy received the higher rank followed by ATO and MTS, and DTO. Moreover, the sensitivity analysis was performed between the alternatives rating and other ANP elements as presented in Figure 6. It was found that changing the priority of any factor has no effect on the alternatives ranking. The ranking was found stable as SBH, MTS, ATO, and DTO respectively. Therefore, SBH is considered as the most suitable Leagile strategy for all housing supply factors.

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340



a) ATO priority=0.5 *b) ATO priority=0.1*

Figure 5. Sensitivity graphs for the reliability of Leagile strategies when ATO priority is 0.5 and 0.1

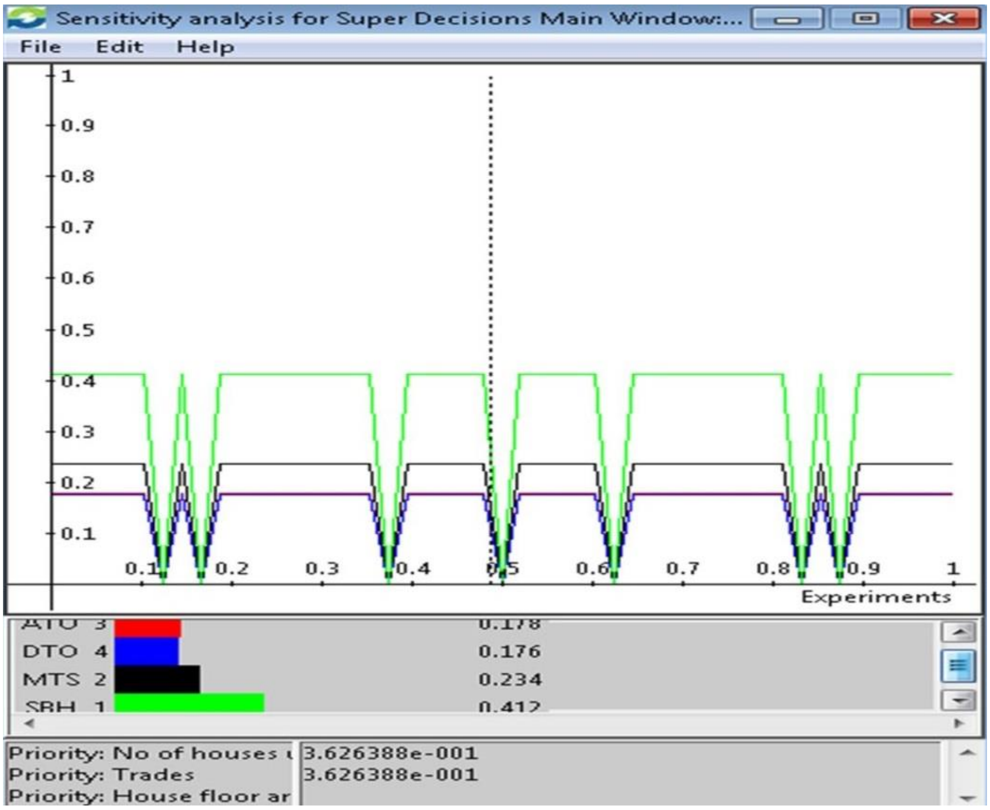


Figure 6. Sensitivity graph between alternatives and other ANP model factors

7.2 Implications of the ANP model

The results from the examination of the ANP model showed that SBH strategy performed most effectively among the four factors affecting the housing supply in Australia. The SBH strategy could be suggested to Australian house builders according to the research results as the strategy that is the most suitable under different combinations of housing supply factors. These results are supported by the HIA (2013) report the showed that the largest 100 builders commenced about 36% of all residential dwellings in Australia during 2012-2013which indicates that 64% of all residential dwellings have been constructed by small builders or in the form of self-building houses. According to the case study of the State of Victoria presented earlier, a group self-build initiative was introduced to support individuals building their own houses (State Government of Victoria, 2014). A key role of OSM in Australia is to supply a variety of house modules and components to house-module suppliers so that OSM could meet the different types of house needs.

The SBH strategy is the best at achieving minimum house cost which enhances the house affordability for low- and medium-income Australians. The research results showed that MTS strategy ranked as the second among the four alternatives. This strategy could be used for mass house building projects where the builders may have to complete the project within a strict contract timeframe. Nevertheless, this research showed that the MTS strategy was the least preferred alternative for house customization. Noticeably, a major drawback of the MTS strategy is the fact that it offers low/no house customization options. However, the strategy may be suitable for the construction of standard house designs.

7.3 Limitations and future research

This study utilized the actual specifications data from 258 houses built by the top five Australian builders. Each specification was extracted and placed according to the categories established. The development of the ANP model in this study was subject to the data released by the builders and secondary data sources on Australian house building. More housing undersupply factors could be further discovered and added to a future study to extend the research boundaries. Other factors such as coordination among the stakeholders, land supply, and demographic factors (e.g., economic circumstances of household, number of overseas migrations) may be included. Moreover, future research could conduct surveys with the Australian house building experts (e.g., house builders, residential developers, architects, and house owners) in order to verify or to refine the ANP model displayed in this study.

8. Conclusions

The Australian house building sector has experienced a shortage in housing supply. The house customer preferences, house building costs, completion time and level of skilled labor add more complexities to the design specifications. Furthermore, house customer demands are ambiguous and change dynamically. The four strategies proposed in this paper attempted to respond to the factors causing supply shortage and to balance the trade-offs between needs of house builders and customers. This study was carried out using the ANP model to facilitate the selection of the Leagile OSM strategies with respect to the main factors contributing to the shortage of housing supply in Australia. The findings from the ANP model indicated that SBH was the most suitable strategy among the four strategies proposed for the combination of factors tested. Therefore, this strategy should be suggested to the Australian house builders.

REFERENCES

Abdelhamid, T. (2004). *The self-destruction and renewal of lean construction theory: a prediction from Boyd's Theory*. Paper presented at the Proceedings of 12th Annual Conference of the International Group for Lean Construction, Copenhagen, Denmark.

ABS. (2012). *2012 Year Book Australia*. Canberra, ACT: Australian Bureau of Statistics.

ABS. (2014). *Average dwelling completion times*. In A. B. o. Statistics (Ed.), Building Activity, Australia. Canberra: ABS.

Agarwal, A., Shankar, R., & Tiwari, M. K. (2006). Modeling the metrics of lean, agile and leagile supply chain: An ANP-based approach. *European Journal of Operational Research, 173(1),* 211-225. doi: 10.1016/j.ejor.2004.12.005

Agarwal, A., Shankar, R., & Tiwari, M. K. (2007). Modeling agility of supply chain. *Industrial Marketing Management, 36(4),* 443-457. doi: 10.1016/j.indmarman.2005.12.004

Arif, M., & Pannell, I. (2013). *Delivering New Homes – The Offsite Way*. Salford UK: Buildoffsite.

Armacost, R. L., Componation, P. J., Mullens, M. A., & Swart, W. W. (1994). An AHP framework for prioritizing customer requirements in QFD: an industrialized housing. *IIE Transactions, 26(4),* 72-79. doi: 10.1080/07408179408966620

Barlow, J., Childerhouse, P., Gann, D., Hong-Minh, S., Naim, M., & Ozaki, R. (2003). Choice and delivery in housebuilding: lessons from Japan for UK housebuilders. *Building Research & Information, 31(2),* 134-145. doi: 10.1080/09613210302003

Barlow, J., & Ozaki, R. (2005). Building mass customised housing through innovation in the production system: lessons from Japan. *Environment and Planning A, 37(1),* 9-20. doi: 10.1068/a3579

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

Bijan, Y., Keramati, A., & Salehi, M. (2014). Comparison of user satisfaction of ecommerce websites by the Analytic Network Process. *International Journal of the Analytic Hierarchy Process, 5(2),* 223-251. doi: http://dx.doi.org/10.13033/ijahp.v5i2.180

Bildsten, L., Björnfot, A., & Sandberg, E. (2011). Value-driven purchasing of kitchen cabinets in industrialised housing. *Journal of Financial Management of Property and Construction, 16(1),* 73-83. doi: 10.1108/13664381111116106

Blismas, N. (2007). Off-site manufacture in Australia: Current state and future directions. Brisbane, QLD: Cooperative Research Centre for Construction Innovation.

Blismas, N., & Wakefield, R. (2009). Drivers, constraints and the future of offsite manufacture in Australia. *Construction Innovation: Information, Process, Management, 9(1),* 72-83. doi: 10.1108/14714170910931552

Chandler, D. (2014). A case for an Australian Construction Strategy, Commonwealth Government Productivity and Industry discussion paper (Discussion Paper). Retrieved 20 October 2014, from ConstructionEdge http://constructionedge.com.au/a-case-for-an-australian-construction-strategy/

Chang, A. S., & Lee, K. P. (2004). *Nature of construction technology*. Paper presented at the Proceedings of the 12th Annual Conference of the IGLC, Elsinore , Denmark.

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

Christopher, M., & Towill, D. (2001). An integrated model for the design of agile supply chains. *International Journal of Physical Distribution & Logistics Management, 31(4),* 235-246. doi: 10.1108/09600030110394914

Christopher, M., & Towill, D. R. (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.

Dalton, T., Hurley, J., Gharaie, E., Wakefield, R., & Horne, R. (2013). *Australian suburban house building: industry organisation, practices and constraints* (A. H. a. U. R. Institute, Trans.). Melbourne, Australia: Australian Housing and Urban Research Institute.

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

Daly, G. (2009). *Prefabricated housing Australia: skill deficiencies and workplace practice*. Melbourne: International Specialised Skills Institute.

Daneshgari, P. (2010). *Agile construction for the electrical contractor*. Sudbury, MA: Jones & Bartlett Learning.

DEEWR. (2012*). Skill Shortages in Construction Trades 2012* (E. a. W. R. Department of Education, Trans.). Canberra: Department of Education, Employment and Workplace Relations.

DeVor, R., Graves, R., & Mills, J. J. (1997). Agile manufacturing research: accomplishments and opportunities. *IIE Transactions, 29(10),* 813-823. doi: 10.1080/07408179708966404

Dowling, R. (2005). Residential building in Australia, 1993–2003. *Urban Policy and Research, 23(4),* 447-464.

Forbes, L. H., & Ahmed, S. M. (2011). *Modern construction : lean project delivery and integrated practices*. Boca Raton, FL: CRC Press.

Gann, D. M. (1996). Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan. *Construction Management and Economics, 14(5),* 437-450. doi: 10.1080/014461996373304

Gibb, A., & Isack, F. (2003). Re-engineering through pre-assembly: client expectations and drivers. *Building Research & Information, 31(2),* 146-160. doi: 10.1080/09613210302000

Goulding, J., Nadim, W., Petridis, P., & Alshawi, M. (2012). Construction industry offsite production: A virtual reality interactive training environment prototype. *Advanced Engineering Informatics, 26(1),* 103-116. doi: http://dx.doi.org/10.1016/j.aei.2011.09.004

Gunasekaran, A., Tirtiroglu, E., & Wolstencroft, V. (2002). An investigation into the application of agile manufacturing in an aerospace company. *Technovation, 22(7),* 405-415. doi: http://dx.doi.org/10.1016/S0166-4972(01)00039-6

Hampson, K. D., & Brandon, P. (2004). *Construction 2020-A vision for Australia's property and construction industry*. Brisbane, QLD: CRC Construction Innovation.

Hamzeh, F., Ballard, G., & Tommelein, I. (2012). Rethinking lookahead planning to optimize construction workflow. *Lean Construction Journal*, 15-34.

HIA. (2014). Housing 100 : Australia's Largest Homebuilders and Residential Developers 2013/2014. In H. E. Group (Ed.), *Housing 100*. Campbell ACT: Housing Industry Association.

Höök, M., & Stehn, L. (2008). Applicability of lean principles and practices in industrialized housing production. *Construction Management and Economics, 26(10),* 1091-1100. doi: 10.1080/01446190802422179

Johnsson, H., & Meiling, J. H. (2009). Defects in offsite construction: timber module prefabrication. *Construction Management and Economics, 27(7),* 667-681. doi: 10.1080/01446190903002797

Kenley, R. (2014). Productivity improvement in the construction process. *Construction Management and Economics*, *32(6),* 489-494. doi: 10.1080/01446193.2014.930500

Khalfan, M. M. A., & Maqsood, T. (2014). Current atate of off-site manufacturing in Australian and Chinese residential construction. *Journal of Construction Engineering, 2014,* 1-5. doi: http://dx.doi.org/10.1155/2014/164863

Koskela, L. (1992a). Application of the new production philosophy to construction *CIFE Technical Report (Stanford University), 72*, 81.

Koskela, L. (1992b). Application of the new production philosophy to construction (D. o. C. E. Center for Integrated Facility Engineering, Trans.). Stanford University, CA.

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

Lessing, J. (2006). *Industrialised house-building - concept and processes.* (Licentiate Thesis), Lund, Sweden: Lund University.

Liu, J., & London, K. (2011). Analysing the relationship between new housing supply and residential construction costs with regional heterogeneities. *Australasian Journal of Construction Economics and Building, 11(3),* 58-67. doi: 10.5130/ajceb.v11i3.2174

Lu, N. (2009). *The current use of offsite construction techniques in the United States construction Industry*. Proceedings of the Construction Research Congress 2009, 946-955. doi: 10.1061/41020(339)96

Lu, N., & Liska, R. W. (2008). Designers' and general contractors' perceptions of offsite construction techniques in the United State construction industry. *International Journal of Construction Education and Research, 4(3),* 177-188. doi: 10.1080/15578770802494565

Manley, K., Mckell, S., & Rose, T. (2009*). Innovative practices in the Australian built environment sector: An information resource for industry* (C. R. C. f. C. Innovation, Trans.) Brisbane, QLD: Built Environment Industry Innovation Council.

Mason-Jones, R., Naylor, B., & Towill, D. R. (2000). Lean, agile or leagile? Matching your supply chain to the marketplace. *International Journal of Production Research, 38(17),* 4061-4070. doi: 10.1080/00207540050204920

Mason-Jones, R., & Towill, D. R. (1999). Total cycle time compression and the agile supply chain. *International Journal of Production Economics, 62(1),* 61-73. doi: http://dx.doi.org/10.1016/S0925-5273(98)00221-7

McGrath-Champ, S., & Rosewarne, S. (2009). Organizational change in Australian building and construction: rethinking a unilinear 'leaning'discourse. *Construction Management and Economics, 27(11),* 1111-1128.

MHRA. (2003). *Technology roadmap for manufactured housing* (U. S. D. o. H. a. U. Development, Trans.). New York: Partenrship for Advanced Technology in Housing.

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

Mostafa, S., Dumrak, J., & Soltan, H. (2013). A framework for lean manufacturing implementation. *Production & Manufacturing Research, 1(1),* 44-64. doi: 10.1080/21693277.2013.862159

Nadim, W., & Goulding, J. S. (2011). Offsite production: a model for building down barriers: A European construction industry perspective. *Engineering, Construction and Architectural Management, 18(1),* 82-101. doi: 10.1108/09699981111098702

Naim, M., & Barlow, J. (2003). An innovative supply chain strategy for customized housing. *Construction Management and Economics, 21(6),* 593-602. doi: 10.1080/0144619032000134129

Naim, M., Naylor, J., & Barlow, J. (1999). *Developing lean and agile supply chains in the UK housebuilding industry*. Paper presented at the Proceedings of the 7th Annual Conference of the IGLC, Berkeley.

Naylor, B. J., Naim, M. M., & Berry, D. (1999). Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain. *International Journal of Production Economics, 62(1–2),* 107-118. doi: 10.1016/s0925-5273(98)00223-0

NHSC. (2013). *Housing supply and affordability issues 2012-13*. Canberra: National Housing Supply Council.

Olhager, J. (2013). Evolution of operations planning and control: from production to supply chains. *International Journal of Production Research*, 1-8. doi: 10.1080/00207543.2012.761363

Ozdemir, M. S. (2005). *The unknown in decision making: The case of a network.* Paper presented at the The Proceedings of the 8th International Symposium on the Analytic Hierarchy Process: Multi-criteria Decision Making, Honolulu, Hawaii, USA.

Pan, W., & Goodier, C. (2012). House-building business models and off-site construction take-up. *Journal of Architectural Engineering, 18(2),* 84-93. doi: doi:10.1061/(ASCE)AE.1943-5568.0000058

Pasquire, C. (2012a). *The 8th flow - common understanding.* Paper presented at the Proceedings of the 20th Annual Conference of the International Group for Lean Construction, San Diego State University, USA.

Pasquire, C. (2012b). Positioning Lean within an exploration of engineering construction. *Construction Management and Economics, 30(8),* 673-685. doi: 10.1080/01446193.2012.689431

PATH. (2002). Technology roadmap: whole house and building process redesign, one year progress report. In Prepared for US Department of Housing and Urban Development (Ed.), *Partenership for Advanced Technology in Housing*. Washington DC, USA: Office of Policy Development and Research.

Purvis, L., Gosling, J., & Naim, M. M. (2014). The development of a lean, agile and leagile supply network taxonomy based on differing types of flexibility. *International Journal of Production Economics, 151*, 100-111. doi: http://dx.doi.org/10.1016/j.ijpe.2014.02.002

Saaty, T. L. (1980). *The Analytic Hierarchy Process : planning, priority setting, resource allocation*. London: McGraw-Hill International Book Co.

Saaty, T. L., & Shang, J. S. (2007). Group decision-making: Head-count versus intensity of preference. *Socio-Economic Planning Sciences, 41(1),* 22-37. doi: http://dx.doi.org/10.1016/j.seps.2005.10.001

Saaty, T. L., & Sodenkamp, M. (2008). Making decisions in hierarchic and network systems. *International Journal of Applied Decision Sciences, 1(1),* 24-79. doi: 10.1504/IJADS.2008.017952

Sarkis, J. (2003). Quantitative models for performance measurement systems—alternate considerations. *International Journal of Production Economics*, *86(1),* 81-90. doi: http://dx.doi.org/10.1016/S0925-5273(03)00055-0

Sertyesilisik, B. (2014). Lean and agile construction project management: As a way of reducing environmental footprint of the construction industry. In H. Xu & X. Wang (Eds.), *Optimization and Control Methods in Industrial Engineering and Construction* (pp. 179-196). Netherlands:Springer.

Shah, R., Chandrasekaran, A., & Linderman, K. (2008). In pursuit of implementation patterns: the context of Lean and Six Sigma. *International Journal of Production Research, 46(23),* 6679-6699. doi: 10.1080/00207540802230504

Shah, R., & Ward, P. (2003). Lean manufacturing: context, practice bundles, and performance. *Journal of Operations Management, 21(2),* 129-149. doi: 10.1016/s0272-6963(02)00108-0

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

Sharp, J. M., Irani, Z., & Desai, S. (1999). Working towards agile manufacturing in the UK industry. *International Journal of Production Economics, 62(1–2),* 155-169. doi: http://dx.doi.org/10.1016/S0925-5273(98)00228-X

State Government of Victoria. (2014). Group self build, housing and community building. *Housing & Community Building: Finance & Business Services.* Retrieved 29/04/2014, 2014, from http://www.dhs.vic.gov.au/for-individuals/housing-and-accommodation/home-owner-support/group-self-build

Towill, D., & Christopher, M. (2002). The supply chain strategy conundrum: To be lean or sgile or to be lean snd sgile? *International Journal of Logistics Research and Applications, 5(3),* 299-309. doi: 10.1080/13675560210000026736

Vidalakis, C., Tookey, J. E., & Sommerville, J. (2013). Demand uncertainty in construction supply chains: a discrete event simulation study. *Journal of the Operational Research Society, 64(8),* 1194-1204. doi: doi.org/10.1057/jors.2012.156

Womack, J., & Jones, D. (2003). *Lean thinking: banish waste and create wealth in your corporation*. London: Free Press.

Yusuf, Y. Y., Sarhadi, M., & Gunasekaran, A. (1999). Agile manufacturing: The drivers, concepts and attributes. *International Journal of Production Economics, 62(1–2),* 33-43. doi: http://dx.doi.org/10.1016/S0925-5273(98)00219-9

Zhang, D., & Sharifi, H. (2007). Towards theory building in sgile manufacturing dtrategy-A taxonomical spproach. *IEEE Transactions on Engineering Management, 54(2),* 351-370. doi: 10.1109/TEM.2007.893989

Appendix A
Unweighted Supermatrix

		Alternatives				**C1**		**C2**		**C3**			**C4**	
		A1	A2	A3	A4	C1.1	C1.2	C2.1	C2.2	C3.1	C3.2	C3.3	C4.1	C4.2
Alternatives	ATO	0.00	0.00	0.00	0.00	0.00	0.13	0.16	0.17	0.19	0.16	0.19	0.17	0.00
	DTO	0.00	0.00	0.00	0.00	0.00	0.08	0.14	0.08	0.24	0.27	0.21	0.24	0.00
	MTS	0.00	0.00	0.00	0.00	0.00	0.37	0.27	0.33	0.12	0.14	0.14	0.00	0.00
	SBH	0.00	0.00	0.00	0.00	0.00	0.42	0.42	0.42	0.46	0.42	0.45	0.00	0.00
C1	C1.1	0.67	0.67	0.50	0.50	0.00	1.00	0.00	0.00	00.00	0.00	0.00	00.00	0.00
	C1.2	0.33	0.33	0.50	0.50	0.00	0.00	0.00	0.00	0.00	00.00	0.00	0.00	00.00
C2	C2.1	0.33	0.25	0.20	0.25	0.00	0.00	0.00	0.00	00.00	00.00	0.00	0.00	00.00
	C2.2	0.67	0.75	0.80	0.75	0.00	0.00	1.00	0.00	0.00	00.00	0.00	0.00	00.00
C3	C3.1	0.31	0.41	0.33	0.26	0.00	0.00	0.00	0.00	00.00	0.50	0.00	0.00	00.00
	C3.2	0.20	0.33	0.33	0.41	0.00	0.00	0.00	0.00	00.00	0.00	0.00	00.00	0.00
	C3.3	0.49	0.26	0.34	0.33	0.00	0.00	0.00	0.00	00.00	0.50	0.00	0.00	00.00
C4	C4.1	0.50	1.00	0.50	0.25	0.00	0.00	0.00	0.00	00.00	0.00	0.00	00.00	0.00
	C4.2	0.50	0.00	0.50	0.75	0.00	0.00	0.00	0.00	00.00	0.00	0.00	1.00	0.00

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

Appendix B
Weighted Supermatrix

		Alternatives				C1		C2		C3			C4	
		A1	A2	A3	A4	C1.1	C1.2	C2.1	C2.2	C3.1	C3.2	C3.3	C4.1	C4.2
Alternatives	ATO	0.00	0.00	0.00	0.00	0.00	0.06	0.08	0.17	0.18	0.08	0.19	0.10	0.00
	DTO	0.00	0.00	0.00	0.00	0.00	0.04	0.07	0.08	0.24	0.13	0.21	0.19	0.00
	MTS	0.00	0.00	0.00	0.00	0.00	0.18	0.13	0.33	0.12	0.07	0.14	0.08	0.00
	SBH	0.00	0.00	0.00	0.00	0.00	0.21	0.21	0.42	0.46	0.21	0.45	0.12	0.00
C1	C1.1	0.12	0.12	0.09	0.09	0.00	0.50	0.00	0.00	00.00	0.00	0.00	00.00	0.00
	C1.2	0.06	0.06	0.09	0.09	0.00	0.00	0.00	0.00	0.00	00.00	0.00	0.00	00.00
C2	C2.1	0.09	0.07	0.06	0.07	0.00	0.00	0.00	0.00	00.00	00.00	0.00	0.00	00.00
	C2.2	0.19	0.21	0.22	0.21	0.00	0.00	0.50	0.00	0.00	00.00	0.00	0.00	00.00
C3	C3.1	0.08	0.10	0.08	0.06	0.00	0.00	0.00	0.00	00.00	0.25	0.00	0.00	00.00
	C3.2	0.05	0.08	0.08	0.10	0.00	0.00	0.00	0.00	00.00	0.00	0.00	00.00	0.00
	C3.3	0.12	0.06	0.08	0.08	0.00	0.00	0.00	0.00	00.00	0.25	0.00	0.00	00.00
C4	C4.1	0.15	0.30	0.15	0.07	0.00	0.00	0.00	0.00	00.00	0.00	0.00	00.00	0.00
	C4.2	0.15	0.00	0.15	0.22	0.00	0.00	0.00	0.00	00.00	0.00	0.00	0.50	0.00

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340

Appendix C
Limit Matrix

		Alternatives				**C1**		**C2**		**C3**			**C4**	
		A1	A2	A3	A4	C1.1	C1.2	C2.1	C2.2	C3.1	C3.2	C3.3	C4.1	C4.2
Alternatives	ATO	0.07	0.07	0.07	0.07	0.00	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.00
	DTO	0.07	0.07	0.07	0.07	0.00	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.00
	MTS	0.09	0.09	0.09	0.09	0.00	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.00
	SBH	0.16	0.16	0.16	0.16	0.00	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.00
C1	C1.1	0.07	0.07	0.07	0.07	0.00	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.00
	C1.2	0.04	0.04	0.04	0.04	0.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04	00.00
C2	C2.1	0.03	0.03	0.03	0.03	0.00	0.03	0.03	0.03	0.03	00.00	0.00	0.00	00.00
	C2.2	0.12	0.12	0.12	0.12	0.00	0.12	0.12	0.12	0.12	0.12	0.12	0.12	00.00
C3	C3.1	0.05	0.05	0.05	0.05	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	00.00
	C3.2	0.04	0.04	0.04	0.04	0.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.00
	C3.3	0.05	0.05	0.05	0.05	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	00.00
C4	C4.1	0.07	0.07	0.07	0.07	0.00	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.00
	C4.2	0.12	0.12	0.12	0.12	0.00	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.00

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v7i3.340