AN AHP MODEL FOR MATCHING LEAGILE STRATEGIES FOR THE OFF-SITE MANUFACTURE IN AUSTRALIA

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ABSTRACT

Australian housing supply has not been responsive commensurately to the growing demand. The residential sector challenges this issue by actively developing and effectively using new materials, processes, and practices to strengthen their competitive advantage against other construction sectors. Three main factors affecting the housing supply and demand are house completion time, cost of finished house, and customer preferences. The best current solution could be introducing the lean and agile concepts to manage the off-site manufacture (OSM) house building supply chain. In this paper, four strategies are introduced to balance the trade-offs between the housing supply and demand. This study presents an example on matching the strategies with the imbalance factors in the Australian house building using Analytical Hierarchy Process (AHP). The AHP model was developed using Expert Choice software package. The results from the AHP model show the benefits of each strategy with respect to each factor tested.

Keywords: Australian Housing; OSM; Leagile Strategies; Customer Order Decoupling Point, AHP.

I. INTRODUCTION

The construction industry is a key economic component of Australia. The productivity of the industry has been continuously expanding. It was accounted for 7.7 per cent of the country’s gross domestic product (GDP) with the gross value added (GVA) reached AUD
102 billion in the financial year 2010-2011 [1]. Australian construction industry includes the private and public sectors that are engaged in three broad activities; residential building, non-residential building, and engineering construction. In Australia, the residential building contributed significantly to the national economy with the overall production value as reported at AUD 47 billion in 2010 and 2011. The Australian residential sector involves many independent building organisations to construct separate houses and other residential buildings including semi-detached houses, townhouses, flats, units and apartments. Nevertheless, the values of work commenced in residential building are likely to be less responsive to the growth of other construction activities [1]. This situation may be influenced by housing supply and demand factors. The housing supply has been found not keeping in pace with the housing demand as reported by [2, 3].

Some studies have examined the shortage of housing supply situation [2,4,5,6]. These studies focus mainly on housing demand side rather than the housing supply challenges [7]. This paper, therefore, addresses the undersupply of the Australian housing from both housing supply and demand perspectives. The housing supply should be considered as a chain containing all house building stakeholders. Lack of coordination between the stakeholders and management of this chain may lead to housing shortage [8]. Three main factors contributing to the Australian housing supply and demand imbalance are been identified in this paper. The factors are house price, house completion time and house customisation. The off-site manufacture (OSM) is a modern method of construction which involves two working sites: off-site factory and onsite construction. Elnaas, Gidado, and Ashton [9] highlight the key themes of decision factors to OSM. Time, quality and cost were the highly important themes for adopting OSM in UK. Some studies in Australia focus on the OSM uptake in house building and develop new housing technologies in home building [10-13]. It has been revealed that the opportunities of OSM in Australia are centred on detached housing, high-density multi-residential complexes, and public facilities such as hospitals, schools, and prisons [14].

It is suggested that some manufacturing concepts such as lean and agile can and should to be transferred to house building production [15, 12]. Selecting an appropriate strategy to meet specific housing house supply and demand requires a systematic selection process. This study, additionally, associates four leagile strategies to manage the two working sites of the OSM supply chain. The suggested strategies are Make to Stock (MTS), Make to Order (ATO), Design to Order (DTO), and Self-building Houses (SBH). The strategies aim to improve the overall performance and competitiveness of the Australian housing sector.

The aim of this article is to identify the main factors contributing the imbalance of housing supply and demand, and to match the four leagile strategies with housing supply factors to improve the house building performance in Australia. The analytic hierarchy process (AHP), a multiple-criterion decision making (MCDM) approach developed by Saaty[16], is employed to form the analysis and deliver the most suitable strategy from the obtained data. AHP serves as a framework for prioritising the four leagile building strategies with respect to the studied three factors. This article is structured into seven consecutive sections. After the introduction, the second section reviews the related literature to Australian housing supply and demand, lean, agile and leagile concepts, and OSM house building supply chain. Section three explains the four leagile house building strategies and the related case studies. The fourth section summarises the research methodology. The fifth section introduces the proposed AHP model which is applied to study four strategies using data obtained from the five largest house builders in five Australian states. The sixth section discusses the results delivered by the AHP model. In the final section, the research conclusion is given with recommendations for further research.
II. LITERATURE REVIEW

II. I. FACTORS AFFECTING THE AUSTRALIAN HOUSING SUPPLY AND DEMAND

The Australian housing supply does not respond adequately to the growing demand especially in capital cities [2]. This situation has been confirmed by the housing industry alliances such as the National Housing Supply council (NHSC), Housing Industry Association (HIA), and Master Builders Australia [17]. The latest report on Housing to 2020 produced by HIA [5], indicates the gaps between underlying demand and supply in housing over the periods until 2020 ranging from low-, medium-, and high-build rate scenarios as presented in Fig. 1.

It can be seen from all build rate scenarios that the gaps between demand and supply do exist. 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 respectively. According to a report of NHSC [3], delivering capacity of the public sector in housing supply will sharply decline in the near future as the recent housing outputs evidently decrease from the units produced in the last decades. The Australian housing undersupply is influenced by both housing supply and demand factors. The three main factors include house price, house completion time, and house customisation.

![Projected dwelling shortage at national level](image)

**Figure 1.** Projected dwelling shortage at national level

II. I.I. HOUSE PRICE

The house price refers to residential construction costs, taxes on new housing and land release [7,3]. House price is a critical element determining the new housing construction [7]. In Australia, house prices have increased in all locations at similar rate of growth [2, 18]. According to the Australian Future Tax System (AFTS) report, the median house prices have risen from three times compared to the average household income in 1990 to around five times in 2010 [19]. The house price includes land price and construction costs (material and labour costs) [7]. The Housing Supply and Affordability Reform (HSAR) states that the growth of house prices is driven by the increase in the prices of established houses [2]. However, AFTS [19] views that the construction costs are responsible for a higher proportion of the increase in
house prices in some regions. The study of Liu and London [7] explore the relationship between new housing supply and construction costs in Australia. Their study concludes that construction costs are a key component of the poor performance of the Australian new housing supply.

II. I. II. HOUSE CUSTOMISATION

Customer preferences reflect customising the house design to suit house customer needs. The preferences may vary from person to person based on the residential desirability and acceptability. Customer preferences include the design and location of a house [20]. The house design includes the internal (floor area) and external (façade width) design for the house. The average floor area of the Australian dwellings has been increased. The average floor area of new detached houses increased from 162.4 square meters to 248.0 square meters from 1984 to 2009. Whereas, new other residential dwellings increased from 99.2 square meters to 140.8 square meters [21]. It is evident from an examination of volume builders that double-story houses and more complex street facing façades have increased [22].

II. I. III. HOUSE COMPLETION TIME

The house completion time is a key factor indicating the quality of housing delivery to house customers. The house completion time can be defined as the time period between the first and last physical building activities to produce a house and make it ready for occupation [17]. The average Australian house completion time has increased while the production rate has been relatively stable [4]. The average Australian house completion time rose from 1.8 quarters to 2.4 quarters from 2000 to 2008 [23]. Dalton et al. [17] identify three factors that might explain the lengthening of house completion time. The first factor is the construction method to manage all activities within house building processes. It also includes coordination and scheduling between the stakeholders as house building is generally delivered through a chain of stakeholders Therefore, building a house needs a successful construction method for meeting the planned schedule to deliver the house. The second factor is concerned with the level of skilled labour which affects the quality of a finished house. Most of the house builders employ quality assurance systems. Nevertheless, they have undergone a poor quality record [17]. The construction managers and supervisors have to arrange with the contractors and sub-contractors for remediate defects. The remediation extends the planned construction time of the house. The third factor is the number of houses under construction. The study of Gharaie, Wakefield, and Blismas [24] shows a positive correlation between the number of houses under construction and completion time.

II.II. OFF-SITE MANUFACTURE

Off-site manufacture (OSM) is a modern method of construction which has been adopted to improve the performance of house building industry [25]. It refers to the production of house components in an off-site factory as well as their subsequent activities in a construction site [26]. OSM provides several benefits to all stakeholders involved in the house building process [10]. It improves onsite safety by providing cleaner and tidier environment to the construction site as well as enhances quality of the house components under factory production. Moreover, OSM reduces environmental effects by reducing waste generation, shortening lead time and increasing the efficiency and productivity [27-29]. There are four categories of OSM based on the degree of off-site works including component manufacture and sub-assembly, non-volumetric pre-assembly, volumetric pre-assembly, and modular building [30,31] as shown in Table 1.
Table 1. Four categories of OSM.

<table>
<thead>
<tr>
<th>Level</th>
<th>Category</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Component manufacture and sub-assembly</td>
<td>Items always made in a factory and never considered for onsite construction (e.g. door furniture, windows)</td>
</tr>
<tr>
<td>2</td>
<td>Non-volumetric pre-assembly</td>
<td>Pre-assembled units which do not enclose usable space (e.g. cladding wall panels, structural frames)</td>
</tr>
<tr>
<td>3</td>
<td>Volumetric pre-assembly</td>
<td>Pre-assembled units which enclose usable space and are typically fully factory finished internally, but do not form the buildings structure (e.g. toilet pods, shower rooms)</td>
</tr>
<tr>
<td>4</td>
<td>Modular building</td>
<td>Pre-assembled volumetric units which also form the actual structure and fabric (e.g. prison blocks, motels)</td>
</tr>
</tbody>
</table>

In Australia, some studies positively address the OSM. For instance, the Construction 2020 report suggested OSM as a key vision for improving the construction industry [11]. Two research projects carried out by Blisma[10] and Manley, McKell, and Rose [32] reveal the future of OSM in the Australian built environment. The findings of the two projects confirmed that OSM has capability to produce high-volume, high-quality houses based on the efficiencies of the manufacturing principles. In spite of the benefits of the OSM, the factory physical production has several forms of non-value added activities or wastes. Ohno[33] enumerate seven forms of waste commonly found in factories physical production are over-production, waiting time, transportation, over-processing, excessive-inventories, defective products, and unnecessary movement. Moreover, the customisation of prefabricated house makes the design specifications become more complex. Such complexity leads to slower response to achieve customer requirements. Three emerging challenges for a construction organisation derive from the management of two working locations simultaneously. 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 [34].

Some attempts have been made to address the shortcomings of OSM house building by adopting successful concepts from the manufacturing industry to house building [13], particularly in lean and agile concepts [35-38]. Lean and agile can manage the OSM supply chain as it does in manufacturing [39]. The combination of lean and agile is known as leagile. In this paper, four leagile strategies are proposed to manage the OSM supply chain as discussed in section three.

II. III. AHP FOR MATCHING LEAGILE STRATEGIES WITH IMBALANCE HOUSING FACTORS

It is contended that the housing supply and demand factors mentioned in the prior sections influence on the shortage situation of Australian housing. Moreover, these factors impact on the selection of house building supply chain strategies. To identify the solutions that can improve the housing shortage situation, AHP is suggested. AHP is a suitable application where the goal and the set of potential criteria and alternatives are made available [40]. AHP is a multiple-criterion decision making (MCDM) developed by Saaty[16] which takes into account of qualitative and quantitative judgements. AHP can be applied by using Expert
Choice© software. The software has advantages including a user friendly environment, an evaluation of inconsistency index of assessments, and a sensitivity analysis of results. The AHP approach assists in evaluating and ranking the leagile strategies of OSM supply chain with respect to the factors.

AHP has widely utilised in many multiple criteria situations including operations management decisions based on customer requirements, construction contractor selection, supplier selection process, improving construction productivity, identifying design development factors in Australian public-project-partnership projects, new product development and infrastructure projects with social impact [41- 47]. AHP facilitates the decision making process by constructing a hierarchical model presenting the integrated levels of the problem from the goal to alternatives [48]. AHP includes two basic components. The first component contains pairwise comparisons among all elements (e.g. criteria, sub criteria, and alternatives) at all levels of the model to make decision on various alternatives. The second component is a synthesis and a ranking of the model elements in order to identify the key elements of the decision making problem [49].

AHP has been used in the construction and house building industry. For instance, Wang et al. [42] use AHP to weight the decision criteria for selecting the best value contractors of two construction projects in Taiwan. Doloi[44] uses AHP to examine the causes of the poor productivity of construction workers in some building construction projects in Melbourne. Wang and Pan [50] propose an AHP model for spotting the factors affecting using industrialised house in Wuhan cityin China. Their model comprised four factors government, enterprise, custom and market. However, the model was not included any strategy for overcoming the impacts caused by these factors.

In this study, AHP is employed to match the four leagile strategies with the three main factors contribute to the Australian housing imbalance. The goal (selecting appropriate house building strategy) is stated and the set of criteria (housing supply and demand imbalance factors) and alternatives (four leagile strategies) are determined. The house building activities from commencing the house building until the house is completed and ready for occupation are in focus. It is because, in the Australian housing context; the number of dwellings completed is less than number of dwellings commenced [1, 51]. Therefore, this paper identified the main factors influence Australian housing imbalance situation and associates the factors with the four suggested strategies.

III. LEAGILE STRATEGIES FOR OSM HOUSE BUILDING SUPPLY CHAIN

Three approaches to operate a supply chain are lean, agile, and Leagile [52]. Lean approach was first developed in the Toyota production system (TPS). Lean is an integrated socio-technical system comprising of management practices that can be applied to eliminate the waste [53]. Lean thinking as an application into the construction environment was first discussed by Koskela in 1992 [54]. A transformation-flow-value concept of production has been developed as a new perspective to improve the construction performance [55]. 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 [56].

Agile concept, on the other hand, became popular in 1991. Sharifi and Zhang [57] state that new competitive environment is a key driver for changes in the manufacturing industry. The competition qualities are continuous improvement, rapid response and quality
The initiative of agile construction was established in direct response to the *Latham Report* published in 1994 [58]. The report highlighted the UK construction industry requirement to reduce the construction cost by 30 per cent by the year 2000. To achieve this target, the whole industry needed to change. Benchmarking has been a method used to stimulate the required change in the construction practices [58]. Naim et al. [38] suggest 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 [59].

The integration of lean and agile is the best solution to answer all the production issues in the world class market competition [60]. Combining lean and agile within the whole supply chain can be accomplished by using the decoupling point (DP). It is known as leagility. The leagility term was firstly introduced by Naylor, Naim, and Berry [61]. In general, the DP separates the leagile supply chain into lean in the upstream and agile in the downstream [62]. For market competition, Christopher and Towill [52] emphasise that supply chains must be responsive to 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. On the contrary, 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 supply chains. The supply chains may be lean prior to DP and agile beyond DP.

There are two DPs in the leagile supply chains [52]. 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 whilst the final assembly or customisation depends on real demand. Leagile supply chain has capabilities to achieve the house customer value through different strategies in accordance with the DP positions. The leagile house building supply chain mainly focuses on waste removal and responsive mechanisms through applying the excellence lean and agile practices. The studies of Childerhouse et al. [53] and Naim and Barlow [15] 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.

The four strategies suggested for leagile house building supply chain are demonstrated in Fig.3. Two supermarkets have been included. The first supermarket stores the house elements and lies between supplier and off-site factory. The second supermarket holds the finished house modules and lies between the off-site factory and construction site. Kanban is used to smooth the flow of manufacturing and construction activities [63]. Kanban is an information and material movement system used to define the type and quantity of parts between processes [64]. The Withdrawal Kanban (WK) is used to authorise movement of material from the two supermarkets while the Production Order Kanban (POK) is used replenish the two supermarkets. Four alternative positions for the CODP which are proposed to be employed in Australian house building supply chain.
III. I. MAKE TO STOCK (MTS) STRATEGY

In MTS strategy, CODP is located after the on-site construction activities and finished house building. This strategy is commonly known as ‘specs’. The houses are designed and built ‘speculatively’ based on the builders’ catalogue [17, 38]. Customers have a choice selection from the available houses based on the location, cost, size, and design. It is found in Barlow and Ozaki [65] that 25 per cent of new houses in Japan are speculative houses. The house customers have less or no choice over the house specifications and designs. The market winner in this strategy is the lower finished house selling price. Panelised house building designed by Monarch Building Systems presented in Blismas [10] is another example of the MTS strategy. The house panels are produced and utilised as standard panels in the company’s building projects. With the MTS strategy, the company can ensure its capacity to serving large-size accommodation projects within the contracted timeframe. Therefore, the activities before selling should be lean to fit the costs. Agile is located after the CODP to diminish the delivery time and to meet the customer satisfaction and the speed of return on investment (ROI) [35].

III. II. ASSEMBLE TO ORDER (ATO) STRATEGY

In ATO strategy, CODP is positioned at the off-site factory. The customer houses are built according to the builder’s catalogues. A variety of house designs are included in the catalogues. Customers have a degree of customisation to select a combination 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 [17]. The house builders’, then, perform the construction activities on-site and assembles the selected modules to complete the house. Two examples of ATO demonstrated in a work of Höök and Stehn [37] are from Swedish construction companies. In the first example, the strategy has
been employed in construction of official and commercial buildings. The second example targets at developing standard modules for multi-family dwelling and students lodgings. Both companies emphasise on encouraging their customers to select building designs within their existing catalogues. Another example of ATO strategy is given in Pan and Goodier [27] from the UK house builders. Classic private house builders are claimed offering their customers with an alteration in house configuration based on the site and geographical areas. The market winners in this strategy are the house pricing and designs of house modules, and the completion time. It is suggested for the ATO strategy to employ lean within the off-site factories. Agile should be employed in stages of shipments and on-site construction to ensure more responsiveness in delivering the houses.

III. III. DESIGN TO ORDER (DTO) STRATEGY

In the 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 own house modules. They have the flexibility to change the predesigned modules to fit their needs. In Japan, about 75 per cent of new detached houses are built on the existing land owned by the house owners. These new houses are designed based on the standard floor plan, but provides the house owner with flexibility to any degree of customization [65]. An example of the DTO strategy comes from Australian experience demonstrated inBlismas [10]. The construction procedure assimilated to the DTO strategy was chosen to build Prep classrooms in the State of Queensland. The design team was obliged to deliver specific features to be incorporated to the modules. Thus, a mock-up and two prototypes were prepared prior to the module production. The modules were, then, produced according to the approved design. The market winner in this strategy is high customisation. Therefore, the house building stages require a combination of lean and agile. Lean is suitable for supplying the material and running the off-site factories whilst other related activities need to be more agile.

III. IV. SELF-BUILDING HOUSE (SBH) STRATEGY

The final strategy is SBH. This strategy is suitable for the self-building houses which a homeowner is intimately 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 [15]. The Australian houses are built by small to large organisations. In 2009, the largest 100 builders commenced approximately 37 per cent of all residential dwellings [17]. Sixty-three per cent of all residential dwellings were constructed either by small builders or in the form of self-building houses. In Victoria State, the Department of Human Services [66] 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 are at their own responsibilities to hire an architect for house designing and builders to assist them with some onsite construction activities. Likewise, the self-building houses model has been adopted in the UK housing sector where approximately 20 per cent of total housing supply is delivered by the house owners with(out) an outsourcing contract for design and built (D&B) [67]. In this strategy, the key role of house building organisations is to supply the house modules and components to the suppliers. House building organisations should aim at making the house assembly as simple as possible. The organisations should provide variable designs to meet different types of house needs. Lean is suitable to run the house modules factory while agile is the best option for quick responses to demands of self-build house suppliers.
IV. RESEARCH METHOD

The use of AHP in this study was to design the model combining the suggested four leagile house building strategies and the key factors contributing to the housing undersupply in Australia. This included selecting and scrutinising a number of possible criteria. Data and information were collected from various resources related to the Australian housing including peer reviewed journals, references books, websites, and Australian housing authorities including 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). The collected materials were carefully examined and allocated reference number. After that, the possible factors (criteria and sub-criteria) affecting the imbalance between housing supply and demand in Australia were determined.

After the AHP model constructed, pairwise comparisons were used to rate all child elements with respect to the parent element according to nine point scale developed by Saaty [16]. 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 Consistency Ratio (CR) less than 0.1 indicates a satisfactory degree of consistency [68]. The new set of acceptable CR values has been modified by Saaty [69] where the values work in association to the size of the matrix. For a 3×3 matrix, 4×4 matrix and larger matrices the CR value should be 0.05, 0.08 and 0.10 respectively. Afterwards, the AHP priorities were generated using the Expert Choice© software. The local priorities were synthesised from the goal while the overall priorities were calculated. The relative weights were used to identify the key factors (criteria and sub-criteria). Moreover, the overall rating of the four house building strategies was determined. After that, a series of sensitivity analyses were performed in the Expert Choice© software to investigate the impact of changing the importance of the criteria on the overall rating of the four strategies.

V. ILLUSTRATIVE EXAMPLE

V. I. THE AHP MODEL

The AHP approach began with constructing the model of the decision problem. The first level was set as the goal of the model. The second level consisted of the three selected criteria: (1) house completion time; (2) house price; and (3) house customisation. Each criterion was further subdivided into eight sub-criteria. The three sub-criteria under house completion time were number of houses under construction, shortage of skilled labour, and construction method. Whereas, two sub-criteria were located under house price construction material and labour costs. Three sub-criteria came under house customisation; house floor area, house location, and façade width. The four strategies were placed at the bottom level of the hierarchy as decision alternatives. After setting all elements of the AHP model, the model was developed using Expert Choice© as shown in Fig.4.

V. II. FOUR LEAGILE STRATEGIES

The imbalance between the housing supply and demand has occurred in all Australian states and territories (COAG, 2012; NHSC, 2012). The Housing 100 Report for 2013 presented the Australia’s the most active 100 builders (HIA, 2013). Their main housing activities contributed around 75 per cent of the housing supply for detached houses and multi-
unit apartments. In this paper, the top five potential builders of supplying houses in five Australian States Western Australia (WA), South Australia (SA), New South Wales (NSW), Victoria (VIC), and Queensland (QLD) were analysed as shown in Table 2.

The five selected potential builders were capable of adopting the four agile strategies. This adopting 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 [5, 22] (HIA, 2011, 2013). Selecting a strategy depends on the situations of house market in Australia. 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 house, less customised and with medium price for the Australian low income groups (increase the 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 strategy for this situation must be carefully determined. The customers have 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 decision 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 3.

V. II. I. PAIRWISE COMPARISONS OF THE MODEL ELEMENTS

Pairwise comparisons were performed to associate the relationships between all elements at all levels of the AHP model. The three criteria were compared with respect to their importance to the goal. Under each criterion, the sub-criteria were compared according to their importance to the criterion. All pairwise numerical comparisons were performed in the expert choice software. The Saaty’s scale allows to compare each two elements in the hierarchy using verbal or numerical judgments as equally (i.e., has a weight of 1), moderately (i.e., has a weight of 3), strongly (i.e., has a weight of 5), very strongly (i.e., has a weight of 7), extremely (i.e., has a weight of 9). The intermediate values are used where appropriate as equally to moderately (i.e., has a weight of 2), moderately to strongly (i.e., has a weight of 4), strongly to very strongly (i.e., has a weight of 6), very strongly to extremely (i.e., has a weight of 8) [70, 16] (Armacost, Componation, Mullens, & Swart, 1994; Saaty, 1980).

An example of pairwise comparison between MTS and ATO strategies respect of houses under construction is demonstrated in Fig.5. The data of each comparison is displayed in a matrix form (e.g. 4x4 matrix in Fig.5). The number of each cell in the matrix represents the relation between two compared elements with respect to the parent element. In Expert Choice, the black coloured numbers means that the criterion on the left hand side is relatively more important than the criterion on the right hand side. Whereas the red coloured numbers appears, it means the criterion on the right is relatively important than the criterion on the left. After completing the pairwise comparisons, all priorities of the AHP model were calculated as shown in Table 4.
**Figure 4.** Proposed AHP model for selecting OSM house building strategy

**Table 2.** Top five Australian house builders attribute [22] (HIA, 2013)

<table>
<thead>
<tr>
<th></th>
<th>Builder A</th>
<th>Builder B</th>
<th>Builder C</th>
<th>Builder D</th>
<th>Builder E</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIA top 100 2012/2013</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>5&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>States</td>
<td>WA</td>
<td>WA, VIC</td>
<td>SA, VIC, NSW, QLD</td>
<td>QLD, VIC, SA</td>
<td>VIC, SA, QLD</td>
</tr>
<tr>
<td>House building activity</td>
<td>Builder</td>
<td>Builder and developer</td>
<td>builder</td>
<td>Builder and developer</td>
<td>Builder</td>
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<tr>
<td>Houses starts during 2013</td>
<td>3443</td>
<td>3199</td>
<td>2837</td>
<td>2432</td>
<td>1692</td>
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<tr>
<td>House market share</td>
<td>13%</td>
<td>12%</td>
<td>10.7%</td>
<td>9.2%</td>
<td>6.4%</td>
</tr>
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<td>Number of models</td>
<td>224</td>
<td>102</td>
<td>60</td>
<td>56</td>
<td>36</td>
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</tbody>
</table>
### Table 3. Leagile strategies’ weighting in each criterion and sub-criteria

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<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C1.1: House floor area</td>
<td>Low</td>
<td>Moderate</td>
<td>Very high</td>
<td>High</td>
</tr>
<tr>
<td>C1.2: House location</td>
<td>Fixed</td>
<td>Flexible</td>
<td>More</td>
<td>Highly</td>
</tr>
<tr>
<td>C1.3: Façade options</td>
<td>Limited</td>
<td>Medium</td>
<td>Large</td>
<td>Moderate</td>
</tr>
<tr>
<td>C2: House price</td>
<td>Low price range</td>
<td>Moderate range</td>
<td>High range</td>
<td>Low-Moderate range</td>
</tr>
<tr>
<td>C2.1: Construction material cost</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>low</td>
</tr>
<tr>
<td>C2.2: Labour cost</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>low</td>
</tr>
<tr>
<td>C3: House completion time</td>
<td>Short</td>
<td>Moderate</td>
<td>Long</td>
<td>Moderate-Short</td>
</tr>
<tr>
<td>C3.1: Number of houses under construction</td>
<td>Few</td>
<td>Moderate</td>
<td>Many</td>
<td>Few</td>
</tr>
<tr>
<td>C3.2: Construction method</td>
<td>Favourable</td>
<td>Medium to High</td>
<td>Neutral</td>
<td>Requires less labour force</td>
</tr>
<tr>
<td>C3.3: Level of skilled labour</td>
<td>Medium labour intensive</td>
<td>High labour intensive</td>
<td>Requires less labour force</td>
<td>Requires less labour force</td>
</tr>
</tbody>
</table>

**Figure 5.** Example of pairwise comparison of two strategies
Table 4. Weighting of the criteria, sub-criteria and alternatives

<table>
<thead>
<tr>
<th>Alternatives (strategies)</th>
<th>ATO</th>
<th>DTO</th>
<th>MTS</th>
<th>SBH</th>
<th>Total Priority of criteria and sub-criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>House completion time</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction method (0.333)</td>
<td>0.011</td>
<td>0.006</td>
<td>0.011</td>
<td>0.039</td>
<td>0.067</td>
</tr>
<tr>
<td>Level of skilled labour (0.333)</td>
<td>0.008</td>
<td>0.005</td>
<td>0.017</td>
<td>0.036</td>
<td>0.066</td>
</tr>
<tr>
<td>Number of houses under construction (0.333)</td>
<td>0.009</td>
<td>0.005</td>
<td>0.022</td>
<td>0.03</td>
<td>0.066</td>
</tr>
<tr>
<td>House completion time (Total Priority)</td>
<td>0.028</td>
<td>0.016</td>
<td>0.05</td>
<td>0.105</td>
<td>0.199</td>
</tr>
<tr>
<td><strong>House customisation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Façade width (0.260)</td>
<td>0.012</td>
<td>0.034</td>
<td>0.009</td>
<td>0.049</td>
<td>0.104</td>
</tr>
<tr>
<td>House floor area (0.413)</td>
<td>0.032</td>
<td>0.016</td>
<td>0.078</td>
<td>0.039</td>
<td>0.165</td>
</tr>
<tr>
<td>House location (0.327)</td>
<td>0.016</td>
<td>0.035</td>
<td>0.008</td>
<td>0.073</td>
<td>0.132</td>
</tr>
<tr>
<td>House customisation (Total Priority)</td>
<td>0.06</td>
<td>0.085</td>
<td>0.095</td>
<td>0.161</td>
<td>0.401</td>
</tr>
<tr>
<td><strong>House price</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labour costs (0.333)</td>
<td>0.013</td>
<td>0.012</td>
<td>0.039</td>
<td>0.069</td>
<td>0.133</td>
</tr>
<tr>
<td>Material costs (0.667)</td>
<td>0.05</td>
<td>0.022</td>
<td>0.122</td>
<td>0.073</td>
<td>0.267</td>
</tr>
<tr>
<td>House price (Total Priority)</td>
<td>0.063</td>
<td>0.034</td>
<td>0.161</td>
<td>0.142</td>
<td>0.400</td>
</tr>
<tr>
<td>Total Priority of alternatives</td>
<td>0.151</td>
<td>0.135</td>
<td>0.306</td>
<td>0.408</td>
<td></td>
</tr>
</tbody>
</table>

For the house completion time criterion, the sub-criteria had the same priority of 0.333. The house customisation sub-criteria priorities were 0.26 for façade width, 0.413 for house floor area and 0.327 for house location. The house price sub-criteria were rating as 0.333 for the labour costs and 0.667 for the material costs. The priorities of the criteria with respect to the goal were calculated. House customisation received the highest priority with 0.401, followed by house price with 0.400 and house completion time with 0.199. The inconsistency index of the judgements was checked to ensure that it is lower than or equal 0.1. Finally, the ranking of the four strategies were calculated with respect to the sub-criteria under each criterion. The weightings of the sub-criteria in each strategy were decided on each strategy adopted by the five builders (see Table 3).

V. II. II. SYNTHESISING THE RESULTS

After pairwise comparisons, the local priorities were synthesised from the goal while the overall priorities were calculated. The overall priorities of the four house building strategies are displayed in Fig.6. The distributive mode was selected. From the test results, the SBH strategy was considered as the best alternative which received the highest rating of 0.407. The second best strategy was MTS which scored 0.306, followed by ATO with a score 0.151. The last one was the DTO strategy with a score of 0.136.
VI. RESULTS AND DISCUSSION

The sensitivity analysis was performed to examine the change results occurred in the priorities of the criteria. A performance summary of each house building strategy interacting with the three factors is shown in Fig.7. Overall, it is projected that the self-build housing (SBH) strategy was considered as the best strategy. However, SBH did not perform as the best strategy on individual criteria. It can be seen from Fig.7 that SBH strategy performed its best in house customisation and house completion time factors while it ranked the second on house price factor. On the other hand, the MTS strategy individually performed its best in house price.
VI. I. THE MAIN CRITERIA FOR STRATEGY SELECTION

The priorities of importance for criteria and sub-criteria under each strategy are presented in Table 4. The house customisation criterion which consisted of sub-criteria, façade width, house floor area, and house location, obtained the highest score of importance (0.401). The second most important criterion was the house price with the score of 0.4. House price contained labour costs (0.133) and material costs (0.267) sub-criteria respectively. On the other hand, house completion time projected as the third important criterion with the score of 0.199. Under this criterion, construction methods (0.067), level of skilled labour (0.066) and number of houses under construction (0.066) were tested.

It can be concluded that house customisation and house price were the most significant criteria for strategy selection according to data obtained in this research from five major builders in Australia. The results provided a clear-sighted on the factors affecting the Australian housing delivery which could lead to the implications and decision making of the house builders based on house customers’ demand. The house completion time, house customisation, and house price are directly affected by the builder strategy to complete a house. The adoption of the leagile strategies will support the uptake of OSM and enhance the house deliver.

VI. II. IMPLICATIONS OF THE MODEL FOR HOUSE BUILDING DECISION

The results from the examination of the proposed AHP model indicated that SBH strategy performed most effectively along the three factors. The SBH strategy could be suggested to the Australian house builders based on the research results that the strategy was the most suitable for the different combinations of the three factors. Furthermore, the results of scenarios demonstration is supported by the AHURI report undertaken by Dalton et al. [17] that 63 per cent of the Australian residential dwellings in 2009 were 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. A key role of OSM in Australia is to supply 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 in achieving minimum house cost which enhances the house affordability for the low- and medium-income Australians.

According to the research results, the MTS strategy ranked the second from overall alternatives. This strategy could be used for mass house building projects where the builders may have to complete the project within the contract timeframe. Nevertheless, this research showed that the MTS strategy was the last alternative for house customisation in the model. A major drawback of the MTS strategy derives from low/none house customisations. The strategy may be suitable only for the construction of standard house designs.

VII. CONCLUSIONS

The Australian house building sector has experienced continuous growth and unmet housing demand. The house customisation, house cost and completion time add more complexities to the design specifications. Furthermore, customer demands are ambiguous and dynamically changed. The four strategies have been proposed in this paper to answer the different situations of demand and balance the trade-off between house builders and customers. This study was carried out using the AHP model to facilitate the selection of the OSM strategies with respect to the three main factors contributing to the imbalance of housing supply and demand in Australia.
For future research, more house builders and housing undersupply factors can be added to the current study. This may include other factors such as coordination and scheduling among the stakeholders, land supply, and demographic factors (e.g., economic circumstances of households, number of overseas migrations). It is important to understand the effects caused by these factors in order to improve the housing delivering system. These nominated criteria have been addressed in the Australian housing supply and demand literature. Therefore, the future study 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 model. Questionnaire and interview surveys may need to be designed using the proposed AHP model.

REFERENCES


[38] M. Naim, J. Naylor, and J. Barlow, Developing lean and agile supply chains in the UK housebuilding industry, proceedings of the 7th Annual Conference of the IGLC, Berkeley, 1999.


[50] Q. Wang, and S. Pan, On Influence Factors of Wuhan Housing Industry Based on the AHP. Systems Engineering Procedia, 3(0), 2012 158-165.


