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Performance and perception in prefab housing: An exploratory industry survey on sustainability and affordability

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Abstract

Provision of adequate and affordable housing is a major challenge in both emerging and industrialised countries. With increasing urgency for addressing climate change and other environmental issues these habitats will need to be environmentally sustainable too. Conventional construction, especially in dense urban centres and in rural or remote areas, is putting great pressures on cost and resource efficiency and is compelling the industry and governments globally to question the approach of business-as-usual. Prefabrication or off-site construction can offer great opportunities for both environmental and economic performance and hence is emerging as an attractive alternative to on-site construction. Although in the established markets the share of prefabrication in overall construction output remains strong, in many countries including Australia it still remains in its infancy. In order to enhance the profile of prefab housing and effectively develop high performance sustainable and affordable housing it is vital that first the needs and perceptions of the industry on these issues are adequately studied. This paper relates to the first of a two part research project aimed at exploring the makeup of the prefab housing industry and identifying various challenges and opportunities. The study was conducted as an international industry survey in which barriers, opportunities, performance and perceptions of sustainability and affordability were explored. The paper presents the results of this survey. Based on a cross-sectional analysis the responses are compared and categorised. Among other things the findings highlight the gaps in our understanding of the relationship between sustainability and affordability. This research contributes to the discourse on the need to better understand the role of design and design decision making for developing high performance prefab housing.

Peer-review under responsibility of the organizing committee iHBE 2016.

Keywords: prefabrication; housing; sustainability; affordability; survey

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1. Introduction

Adequate and affordable housing provision is a global problem challenging emerging economies [1] and established economies, such as Australia, equally [2]. Conventional construction due to its cost impacts is a major barrier to addressing this challenge. Prefabrication (prefab) or industrialisation of construction is offered as one of the key ways to reduce the cost of delivering affordable housing [3]. Building and construction industry also has significant energy, carbon, water, materials, waste and other environmental impacts [4]. Prefab has been shown to provide better environmental outcomes too in addition to having several other benefits, such as time, cost, construction quality, on-site safety, productivity and so on [5-7]. Although in the established markets such as Japan, Austria, Germany, Sweden and other European countries, the share of prefabrication in overall construction output remains strong [8, 9], in many countries, including Australia, it still remains in its infancy [10].

In this context, there is a pressing need to enhance the profile of prefab housing and effectively develop high performance sustainable and affordable housing. For that it is vital that first the gaps and needs of the industry on these issues are adequately studied. Although there is literature on broader industry drivers and constraints [11, 12] as well as on environmental benefits of prefab compared to conventional construction [13-17], there is a need for further exploration into the perceptions and performance of the global prefab housing industry to better understand the relationship between environmental sustainability and economic affordability.

This paper aims to present the findings of an exploratory international survey conducted to capture a snapshot of the prefab housing industry, its various needs and gaps, and its perceptions on sustainability and affordability performance. The paper is structured in three main categories: (a) research methodology, (b) discussion of findings, and (c) conclusion and direction for future research. This research contributes to the discussion on the barriers to greater uptake and application of prefab in general, and on the opportunities for greater sustainability and affordability in prefab housing. But more importantly, it draws attention to industry perceptions on its performance and identifies specific gaps in the area of design and decision support systems that can aid in delivering high performance prefab homes. The research presented in this paper is the first of a two stage research project aimed at developing a framework for decision making with a potential for practical utility in the prefab housing industry.

2. Research methodology

The research methodology was designed to explore the makeup of the prefab housing industry and capture a snapshot of the leading stakeholders' and experts' understanding and perceptions in regards to sustainability and affordability as well as the industry's key constraints and drivers. In order to capture this snapshot a quantitative methodological approach was chosen which involved literature review and a pilot survey leading to an online exploratory international industry survey. This exploratory survey was intended as the first stage of a larger two stage research project aimed to gather a pool of willing prefab housing industry organisations, from which an appropriately representative smaller sample would be chosen for the second stage of this study with an aim to develop a decision support framework for high performance in sustainability and affordability.

2.1. Survey design and distribution

The survey was specifically designed for dissemination and access through internet. The technique used to distribute the questionnaire internationally was a Non-probability Sampling Technique which included a combination of Convenient Sampling and Judgement Sampling techniques. A web-hosted survey program called WorldAPP KeySurvey (v8.6) [18] was used to design, launch and manage the survey as well as to gather response data. A unique URL for the survey was generated and included in an invitation letter that was distributed through emails to relevant industry organisations and associations internationally, through postings on relevant web groups hosted on the professional social media site Linked-In, and via individual emails to several industry experts and leading decision makers. The invitation letter as well as the Project Information Statement, before the beginning of the survey, presented the context of the study along with confidentiality and disclosure statements. It was explained that the survey was the first part of a two stage research project; second stage involving a future survey to gather detailed parametric data for further analysis. Although no recompense was promised, in order to encourage greater

response and as an appreciation of contribution, it was declared that relevant and selected respondents for the second stage of the study would be offered a chance to win one of four gift cards worth $250 (AUD).

The questionnaire itself was divided into two main sections: the first mainly for administrative purpose, which included five questions on respondent identification details and a statement of support in response to the research ethics requirements, and the second as the main part of this survey, which included up to 48 questions. A majority of these (up to 38) included multiple choice or rank on a scale type questions with limited (up to 10) open ended questions. The final number of questions a respondent encountered depended on selections made on earlier questions due to the application of branching logic within several questions. This was done to pose only the relevant questions to the respondent and limit the total number of questions a respondent had to face, keeping the total expected time required for completion to 15 minutes. The main section of the questionnaire was divided in eight distinct parts:

a) About you: This included questions on respondent's role and level of experience
b) About your work: This included questions on geographic location, size of the organisation and market type, type and level of prefabrication and buildings, categories of materials and production systems used, production capacity and time on site
c) About your experience and needs: This included questions on drivers and barriers for prefabrication, and priority areas and needs of their business
d) About sustainability: This included questions on their perception of their buildings' environmental performance within their market, factors contributing to that performance, and how they measure that performance
e) About affordability: This included questions on their perception of their buildings' economic performance in their market, factors contributing to that performance, and pricing mechanism
f) About relationship between sustainability and affordability: This included a question on their perception of where the balance between sustainability and affordability rests in their work
g) About design: This included broad questions on design options offered and their perception and experience on the importance of architectural design as well as of entire manufacturing and assembly/installation process design in achieving sustainability and affordability
h) About decision making: This included questions on their awareness, experience and opinion on decision support systems

2.2. Data collection and analysis

The survey was released for about one year between April 2015 & May 2016. The number of click-through was recorded at 325 with total responses at 164. After eliminating invalid responses (74%), the total number of valid responses received was 43 (26%). The response rate, based on respondents that completed the entire survey, was calculated at 60.5%. The data analysis and final reporting was largely conducted using descriptive statistics and visualisation analytics through MS Excel 2010 with the help of the inbuilt Data Analysis toolpack and MegaStat add-in.

The main limitations of this method of survey dissemination and data collection include availability of internet connection for accessing the web based survey and English language as the medium of survey all partly contributing to a lower response rate. Web based surveys such as this one have been generally considered a low response survey method where it is not unusual to receive less than 20% response rate [19]. It was neither appropriate nor feasible to truly calculate a definitive response rate and non-response rate as the survey was disseminated widely through various platforms. Non-probability Sampling (a mix of Convenient Sampling and Judgement Sampling) method was chosen due to the large size and global spread of the prefab industry (unknown population size). Although this sampling method is prone to issues such as a self-selection bias, non-response, and undercoverage, the overall intention was to capture a snapshot of the prefab industry and its experts' responses on perception and performance in specific areas rather than to draw true generalisation for the entire population and hence it was considered appropriate that the sample was not representative of the entire global prefab industry.

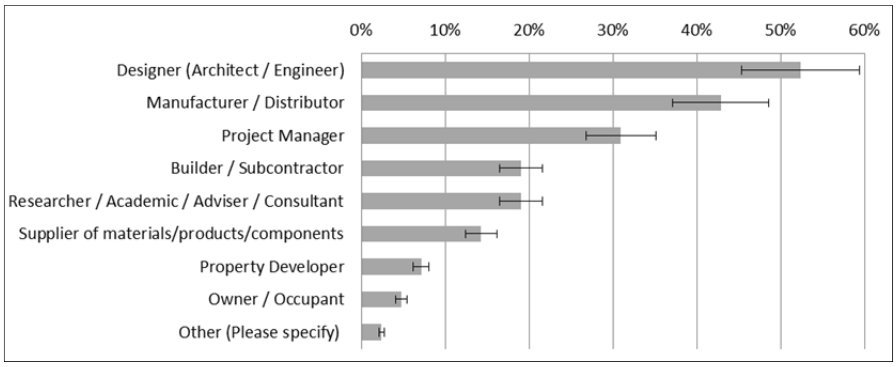

Fig. 1. Respondents' role in prefab industry

2.3. Characteristics of sample set

Out of all valid responses 84% belonged to organisations or companies working in this field. The rest were either academics and researchers or owners/occupants.

Role in the prefab industry and experience: The respondents were allowed to select more than one role and hence the total number of responses would add up to more than 100%. Out of 42 respondents to this question, based on the 95% confidence level and calculated margin of error of 13.36, about half indicated their role as Designers (Architects / Engineers) at 52%, followed by Manufacturers / Distributers at 43%. The remaining respondents included Project Managers, Builders / Subcontractors, Researchers / Academics / Advisers / Consultants, Suppliers, Property Developers as well as Owners / Occupants with descending representation as illustrated in Fig. 1. About two third of respondents had experience of more than 5 years and an estimated 38% indicated more than 10 years of experience in their nominated role.

Countries: In response to the question on country of their manufacturing and supply 27 different countries were identified from all regions including America, Asia Pacific, Europe and Africa. Out of these, manufacturing was occurring in 15 different countries, namely Australia, Brazil, Canada, China, Germany, Ghana, India, Japan, Kenya, Malaysia, Pakistan, Romania, UK, Uruguay and US. A maximum number of respondents out of 43 nominated Australia as their country for manufacturing (35%) and supply (33%). The second highest selection for manufacturing (16%) was China while for supply (7%) was Brazil.

Size of Organisations: The employment profiles also showed the responding organisations varied significantly in size. Out of 42 respondents an estimated 43% employed less than 20 people in their organisation while 24% employed more than 100. A small percent (5%) employed more than 500, which was essentially made up of two respondents, one in the range of 500-1000 and the other above 5000.

3. Discussion of findings

The findings are divided in three main sections: first relating to the participants' experience with specific aspects of prefab building and housing sector, second relating to their perceptions on sustainability and affordability performance, and third relating to their opinions on the needs and gaps of the industry and their own practice. The responses gathered were compared and correlated using simple descriptive statistics tools and presented visually to paint the picture of industry perceptions and performance in key areas.

3.1. Prefabrication and housing

Participants were asked to answer a series of multiple-choice questions in order to capture a snapshot of their experience in the context of prefabrication and housing industry and the market they operate in.

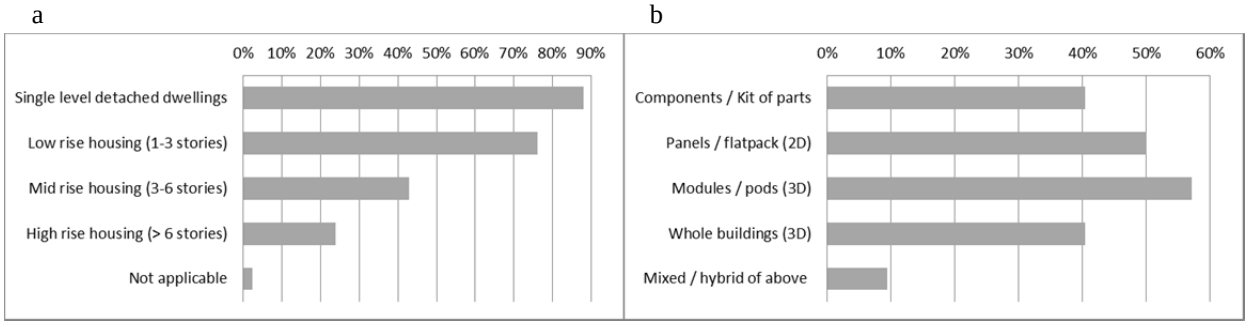

Fig. 2. (a) Housing type; (b) Prefab category

Market and housing type: Participants were asked to select their market type where more than one selection was allowed. Within the residential category, suburban dwellings was the most popular selection for more than half of all respondents. Close to half also indicated involvement in rural dwellings / holiday homes, high-end / boutique / custom designed homes as well as high density urban or city dwellings. An estimated 48% also selected social housing / low-income or low-cost homes. Within the residential category the respondents were asked about the type of housing they had experience with. The most frequent choice was single level detached dwellings at 88% followed by low rise housing, mid-rise housing and high rise housing at 76%, 43% and 24% selections respectively (Fig. 2a).

Category of prefab: More than half of the respondents selected modular systems and exactly half opted for panelised systems. Modular included modules or pods that are essentially three dimensional or volumetric elements, while panelised systems included any system that used panels, cassettes, trays or flat packs that are two dimensional or non-volumetric elements. Both components / kit of parts and whole buildings (3D) were equally popular selections followed by modular and panelised. To a small extent mixed / hybrid systems were also selected by an estimated 10% of the respondents (Fig. 2b).

Construction type: The most frequent selection by far was steel framed construction, which was selected by an estimated 54% of all 41 statistics based responses. Second highest selection at 22% was timber panels / cassettes / trays / SIPs (2D) closely followed by steel panels (2D) and timber framed systems both at an estimated 20%. Timber modular (3D) and precast concrete frames & components were relatively less popular at 15% and 12% respectively. Other construction types nominated include shipping container based modules, aluminum framed and modules, plastic or polymer based frames and panels, concrete panels and modules, and other hybrid materials each with less than 10% response individually.

Production system type and capacity: Out of the 40 responses the most popular selections were predominantly manual fabrication with no assembly line and part manual and part mechanised / robotised work on assembly lines, both selections, achieving an estimated 30% response individually. Almost a quarter of the responses made a selection of predominantly manual fabrication on assembly lines. A small percent of participants (8%) said they use predominantly mechanised / robotised work on assembly lines. When asked about their production capacity the response was quite diverse, ranging from less than 10 to more than 10,000 homes per year as illustrated in Fig. 3a.

Off-site vs. onsite mix: The response was equally wide-ranging when asked about the level of prefabrication usually employed in their projects. The most popular choices as shown in Fig. 3b, were the mid-range of prefabrication, i.e. almost half prefab or off-site work mixed with half onsite construction, and 80-95% prefabrication, both equally at about 22% individually. However, close to a half of all respondents selected higher level of prefabrication than the mid-range and close to 30% preferred prefabrication levels higher than 80%. Almost a quarter of responses chose lower level of prefabrication with one half at 20-40% prefab and the other at only 0-20% prefab with 0-100% onsite construction.

Size of dwellings: Participants indicated experience with all size of dwellings (Fig. 3c). A two bedroom dwelling was the most frequent size selection by almost two thirds of all respondents with decreasing selection on either side of dwelling sizes. The self-contained studio dwellings with no separate bedroom were least popular at an estimated 39% of responses. Under the other category 29% specified that they could deliver any size of dwelling, from as small as 13sqm to as large as 500sqm, with some claiming multi-story dwellings of up to 7 bedrooms.

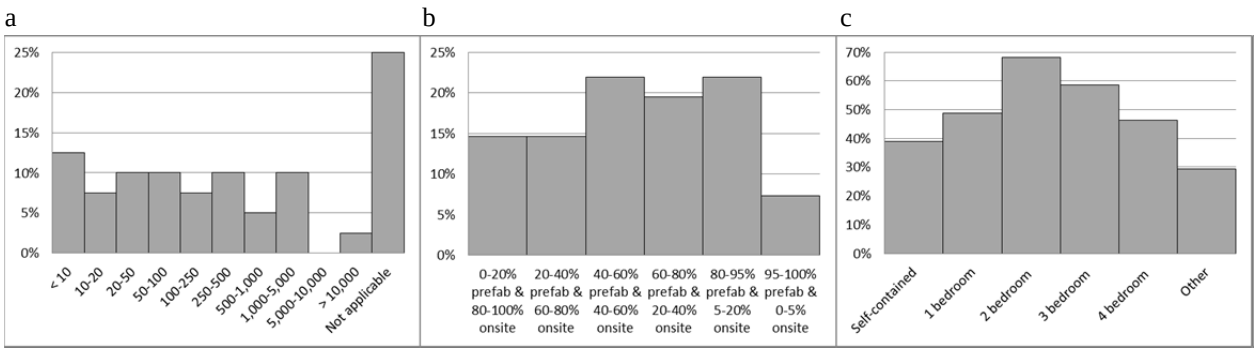

Fig. 3. (a) Production capacity; (b) Level of prefab; (c) Size of dwellings

Time required on site: In order to ascertain the time component of onsite work the participants were asked about the time their projects usually require onsite for assembly or installation and other work before their homes are ready for occupancy. A clear majority of respondents (41%) nominated 4-8 weeks range for their homes followed by 8-12 weeks range by an estimated 27%. Almost a half of all respondents selected the mid-range of between half a week and 4 weeks. A small portion claimed to be requiring even less than half a week with one respondent requiring less than a day indicating a capability to offer extremely high degree of completion of work off-site.

3.2. Performance and perception

The participants were asked a series of questions designed to capture their perceptions on the importance of sustainability and affordability issues and their opinions on their homes' performance on both these criteria within their own market. Out of 28 respondents that answered these questions an estimated 82% claimed that their prefab buildings could be considered environmentally very sustainable (evidently better compared to an expected average performance within their own market). Compared to this an estimated 71% claimed that their buildings be considered economically very affordable.

Environmental sustainability characteristics: In order to ascertain what contributed to these views on environmental sustainability and economic affordability they were asked separate multiple-choice questions on features and characteristics that contribute to sustainability and affordability of those buildings. Out of 13 different choices offered, clearly the most popular feature, at an estimated 78%, was operational energy efficiency through high thermal performance followed by energy efficient fixtures, appliances and equipment by about 61% of the respondents. This correlated with their answers in another question where the respondents claimed that thermal performance simulation based assessment (at about 43%) and whole building energy assessment and rating (at 25%) were by far the topmost two assessments and certifications undertaken. Other characteristics nominated by almost half of the respondents, in a descending order of preference were, overall lifecycle environmental considerations, waste and resource minimisation strategies, water efficient fixtures, appliances and equipment, and environmentally preferable materials. Embodied energy/carbon/water considerations, energy harvesting system (e.g. solar PV), water harvesting systems (e.g. rainwater, greywater), passive solar and/or other innovative sustainable design strategies, and indoor environmental quality (IEQ) considerations were selected within the 20% to 40% range. An estimated 17% of the respondents also acknowledged smaller floor area as one of the characteristics for achieving environmental sustainability.

Economic affordability characteristics: When asked about the aspects of their buildings that contributed to their economic affordability, out of 11 options, the most popular selection (63%) was cost effective materials, followed by standardised or cost effective design solutions, initial purchase (up-front) cost, and operational cost in a descending order of preference, all at more than 40%. The midrange of selection was led by overall lifecycle cost at an estimated 32%, followed by smaller floor area at about 26%. Both lower level of specification and lower quality of finishes and detailing were equally selected by an estimated 21% of respondents. Interestingly, only one participant acknowledged the option of lower range of appliances and equipment, while the option of lower level of construction quality was not taken up by any participant for achieving economic affordability in their buildings.

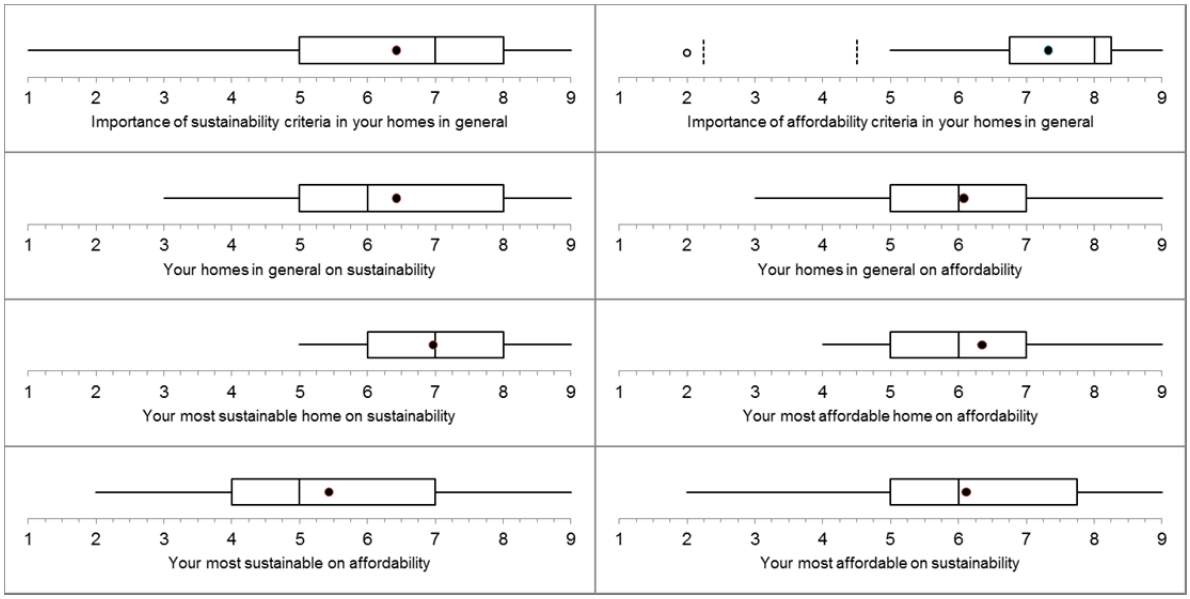

Fig. 4. Range and distribution of participants' responses on their homes' performance on sustainability and affordability

Relationship between sustainability and affordability: This section included a series of 9 point Likert scale questions where 1 represented 'not at all' (e.g. not at all important/sustainable/affordable), 5 represented 'neutral/unsure' and 9 represented 'most' (e.g. most important/sustainable/affordable). First they were asked, in general how important were sustainability criteria in the design and production processes of their homes. Out of 28 responses the most popular answers at 25% each were 5 and 8. As illustrated in Fig. 4 the response was fairly skewed with the values spreading on the entire scale with the interquartile range at 5 to 8 and the median at 7. The average response for the sample was 6.4. On the other hand when asked the same question on affordability criteria the data was significantly leaning towards the upper end of the scale and the median at 8 indicating a tendency for markedly higher preference for and sharp focus on affordability criteria compared to sustainability criteria.

When asked how sustainable they thought their homes in general were compared to other equivalent sized prefab homes in their own market the response was quite similar to their answer on the importance of sustainability. On the question of ranking their homes in general on affordability the trend was reversed. The overall range and the interquartile range while becoming very symmetrical expanded and shifted downwards. This indicated the opinion that the overall affordability performance was markedly lower than their opinion regarding the importance of affordability criteria. When asked how sustainable was their most sustainable home and how affordable was their most affordable home, in both cases understandably, the opinion consolidated further towards the higher end of the scale indicating, of course, that their most sustainable and most affordable homes were better performing than their homes in general. However, this shift was more prominent on the sustainability scale. What was also noticeable was that the most sustainable homes were generally ranked one point higher than the most affordable homes.

In order to capture the perceptions on the relationship between sustainability and affordability the participants were then asked to rank the same most sustainable home on the scale of affordability. The results interestingly indicated a significant drop in the ranking. Both the lower quartile and the median dropped by two points and the lowest observation dropped by three points. This, as distinctly illustrated in Fig. 5, unmistakably reflected a perception that when the homes moved up the scale on sustainability performance their performance dropped on affordability. Surprisingly, when the question was reversed the results were not that straightforward. Although the lowest observation dropped by two points and the mean dropped marginally indicating a downward trend, unexpectedly, the lower quartile and the median remained the same and the upper quartile shifted upward by 0.75 point on the scale of sustainability. This indicated that in the opinion of many participants, as also illustrated in Fig. 5, as the homes improved on affordability, to some extent, their performance on sustainability improved too.

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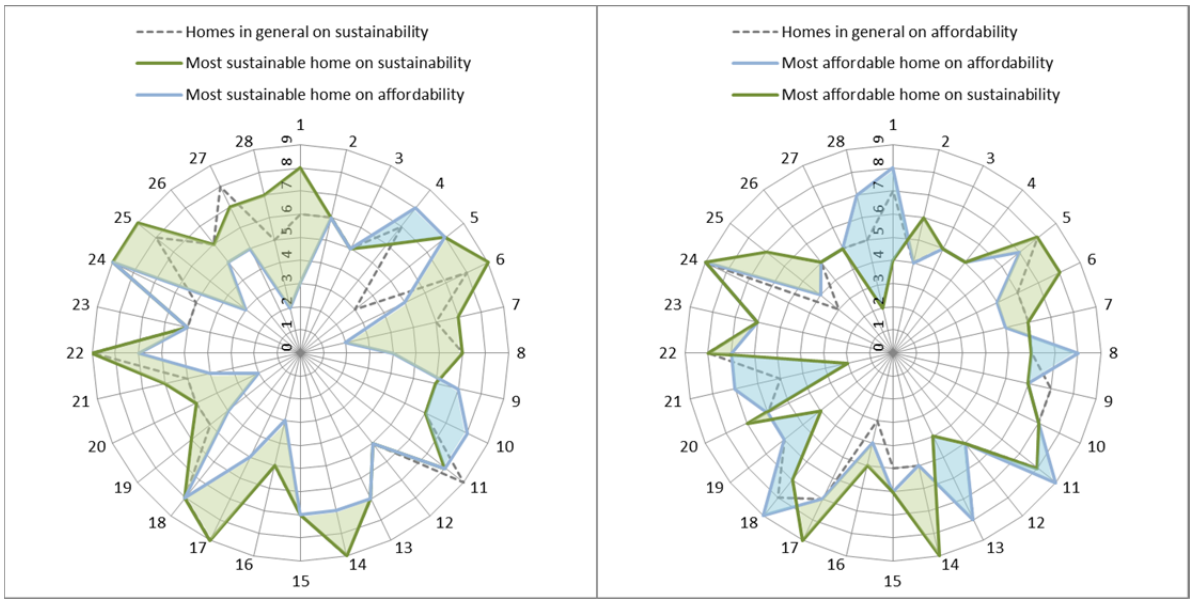

Fig. 5. Respondents' perception of the performance of their homes in general, (a) most sustainable home, and (b) most affordable home

The next stage of research will investigate this pattern further to understand the nature and extent of this co-benefit between affordability and sustainability. Alternatively, the other interpretation could be that those participants whose responses were instrumental to this pattern may be working in a high-end market with their most affordable homes themselves ranking quite low on the affordability scale while at the same time ranking comparatively high on the sustainability scale. If this was the case then it would remain consistent with the results on the most sustainable homes and simply support the earlier findings of apparent contrast between the performances on the scales of sustainability and affordability.

3.3. Needs and gaps

The participants were asked a series of questions aimed at capturing their opinion on the needs and the gaps for both the industry in general and their own businesses. Several of the factors identified within the top constraints for the industry also appeared as the areas where improvements would significantly improve their own business.

Constraints and drivers for the industry: The participants were asked to rank various constraints and drivers for the greater uptake and application of prefabrication in the building industry. The raking was required on a 7 point scale where -3 was significant constraint, -2 was moderate constraint, -1 was minor constraint, 0 was no impact/unsure and 1 to 3 were drivers with 3 being significant driver. Out of 36 different factors provided and based on 33 responses received the highest ranked constraint, at the top of the top five, was the reluctance or lack of awareness / training / experience of Builders, Contractors or Developers at an estimated 39%. The other highly ranked constraints in a descending order were policies of finance industry / banks at about 30%, perception issues in the society and risks in adapting to new processes and systems at 24%, and reluctance or lack of awareness / training / experience of Designers including Architects and Engineers at an estimated 21%. Almost 28% also identified insufficient industry investment in research and development as a second highest ranked moderate constraint.

Among the top five drivers, shorter schedules and high speed of completion as well as shorter on-site duration were by far the most popular drivers at about 59% and 58% respectively. Tighter building envelopes leading to higher thermal performance and energy efficiency, greater construction quality control, remote area infrastructure or site access issues and overall environmental performance throughout lifecycle were the remaining in the top five, each nominated by more than 36% of respondents. Certainty in project completion date and feasibility of product or component repeatability were the highest ranked moderate drivers by 48% and 40% respondents respectively.

Needs of the business: When asked to rank on a five point scale various factors that are likely to benefit their own business most significantly out of 35 options, three were identified as highest ranking. About 50% of the respondents thought improvements in the perception issues in the society or among home buyers, and in reducing overall project duration, cost over entire lifecycle or benefits beyond cost, would provide the highest benefit. More than 40% also desired better thermal performance / energy efficiency, better manufacturing approach (such as lean manufacturing), and further reduced installation cost. Other improvements with higher benefits included mandatory sustainability assessment or certification of buildings, ability to achieve lower initial cost, and improved overall environmental performance throughout lifecycle along with ability to freeze design and specification early.

Design and decision support frameworks: In an earlier research the authors [20] demonstrated how integrative architectural design can have significant influence on the performance of prefab homes. Although a further detailed exploration on that is expected at the next stage, this survey included broad questions on design approaches. On a nine point Likert scale question of how important they considered architectural design of building itself in achieving sustainability and affordability the average response from the 26 respondents was in the range of very important (mean being at 7.4), with an estimated 62% scoring either 8 or 9. While most considered architectural design as important, interestingly, two respondents only ranked it at 4. When asked on the importance of the entire process design (manufacturing and assembly/installation) in delivering the same the average score only rose marginally with median again staying at 8. An estimated 65% acknowledged that design or strategies of design helped them achieve high performance in sustainability and affordability. It was curious to note that about 31% were unsure about it.

In order to ascertain the level of awareness on decision support frameworks, models or tools for strategic guidance on sustainability and/or affordability the respondents were asked a conditional yes and no type question. Nearly 65% said they were not aware of any decision support frameworks and those with a yes were largely using frameworks applicable for buildings in general and not for prefab buildings. Only one reported to being aware of a specially developed framework for prefab buildings. On further questioning almost 77% declared using no decision support framework, model or tool for strategic guidance on sustainability and/or affordability. An estimated only 19% used frameworks for buildings in general and only one respondent used a framework for decision making that was developed for their own prefab buildings. Similarly on a question of BIM use 62% said they did not use BIM. Out of those that used it 31% only used it for building design and only two had full BIM integration across most or all stages. This highlighted a significant gap, which was further emphasised by the fact that nearly 85% of the respondents reported it to be useful if they could have a decision support framework that could aid in design and manufacturing decision making in the context of sustainability and affordability performance. Nearly 62% ranked it within the very useful range of 8 & 9, while 27% ranked it at most useful for their own business.

4. Conclusion and direction for further research

This study was designed to explore the makeup of the prefab housing industry and capture a snapshot of its leading stakeholders' and experts' opinions on the constraints, drivers and needs of the industry to better understand their perceptions and performance on environmental sustainability and economic affordability. The findings suggest that the participants represented diverse backgrounds in terms of their roles and profiles as well as their businesses' experiences and needs. The most popular features for environmental sustainability were operational energy efficiency followed by overall lifecycle environmental considerations. The most popular aspects contributing to economic affordability were cost effective materials and design solutions, initial purchase cost and operational cost.

More importantly, the analysis of the responses revealed a peculiar relationship between sustainability and affordability. While both were considered very important, when compared together the high performing homes indicated an inverse relationship between their performances on each criteria. The results unmistakably reflected a perception that as the homes improved on sustainability their performance dropped on affordability and vice versa. However, the results also indicated that to some extent when the homes improved affordability their sustainability improved too. Whether this indicates the case of co-benefit or simply an earlier identified divergence between affordability and sustainability, it calls for further investigation into this fascinating pattern of relationship.

The reluctance or lack of awareness among Builders and Designers, policies of finance industry/banks, societal perception issues, risks in adapting to new processes and systems, and insufficient industry investment in research

and development were identified as some of the biggest constraints to greater uptake of prefabrication. On the other hand shorter schedules with high speed of completion, higher thermal performance and energy efficiency, greater construction quality control, and overall environmental performance were among the top drivers. The perception issue in the society and among home buyers or clients was perceived to be a top priority area for improvement. Other areas for further improvement included overall project duration, and cost benefit over entire lifecycle. The findings also highlighted a significant gap and the need for appropriate design and decision support frameworks that can aid in delivering high performance sustainable and affordable housing. The specific issues around design including architectural design will be further explored through case studies in the next stage of research.

This research contributes to the discussion on the barriers to greater uptake and application of prefabrication within building industry in general but also specifically on the opportunities for greater sustainability and affordability in housing. It also gathers useful information on what the industry thinks about its performance and identifies specific gaps and needs in the area of design and decision support systems that need to be addressed. It acts as a stepping stone for the next phase of this research which aims at collecting detailed parametric information to develop a framework for decision making with a potential for practical utility for the prefab housing industry.

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