Reshaping housing – the role of prefabricated systems

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Abstract

Prefabricated housing innovations have the potential to reduce the environmental impact of construction through improving efficiency and quality. The current paper systematically summarises the published evidence since 1990 that describes the barriers and drivers affecting the uptake of prefabricated housing innovations. These are discussed in relation to a 'Project-Based Product Framework' which considers multiple stakeholders including builders and other intermediaries, suppliers, end-users, the broader policy context and technical issues. The framework facilitated identification of central issues such as the prevalent business and cultural resistance associated with process changes; the potential for efficiency and quality improvements and cost savings; the simultaneous risks and benefits of close supplier-builder relationships, and negative user perceptions towards prefabricated houses. Though there is a lack of evidence regarding the effects of regulations and government policies on prefabrication uptake, there are indications of the positive potential of financial and social incentives. Directions for further research include understanding how to: manage the industry's transition to prefabricated houses; appropriately compare prefabricated housing to traditional housing on cost, efficiency and quality measures; reconcile the differing perspectives of various stakeholders; quantify and identify the perspectives of the potential end-user population, and manage the interface between the emerging industry and information technology improvements.

Introduction

The potential negative effects of climate change have been well-established in existing literature (Intergovernmental Panel on Climate Change, 2005), with the generation of greenhouse gases being noted as a key contributor. Buildings worldwide account for 40% of global energy consumption with simulations suggesting total energy consumption will increase three-fold if no new policies are adopted (World Business Council for Sustainable Development, 2009). As a subset of all buildings' impact, the construction of new stand-alone residential dwellings in the U.S. has been identified as having as much global warming potential as that for new highway, bridge, office, industrial and commercial construction combined (Hendrickson & Horvath, 2000). Simpson (2000) similarly noted that 10% of an average Australian's ecological footprint can be attributed to housing, with 60% of this due to construction and maintenance.

Prefabricated housing is defined here as the manufacture of whole houses, or significant housing components, offsite in a factory setting prior to installation or assembly onsite. This is a promising innovation with a clear relationship to more environmentally friendly building practices (Hampson & Brandon, 2004). This paper defines prefabricated housing as an innovation because it is new to the majority of participants in the housing market. Traditional building methods, utilising large numbers of sub-teams and individual contractors operating onsite, do not promote efficiency in terms of process, nor do they facilitate accumulation of lessons learnt within a business. Prefabrication on the other hand has the potential to centralise repeatable processes that accumulate knowledge to improve efficiency and quality. An overall rationale for the current research is that achieving efficiency, retaining knowledge, and ensuring the on-going success of the house construction industry is not possible using traditional, onsite construction methods (Halman, Voordijk, & Reymen, 2008).

The concepts of prefabrication and simplification of tasks applied to the construction sector are not new, having been discussed extensively since the 1950's (Branson, Eishennawy, Swart, & Chandra, 1990). A range of related terms are used to describe houses constructed in this manner and each is associated with a particular context as shown in Table 1. The terms 'prefabrication' and 'prefabricated housing' have been adopted throughout the current paper due to their common use and lack of association with any one particular context or construction method. For example, using the term 'manufactured housing' has unintended associations with temporary or mobile housing.

Table 1. *Prefabricated housing terms and their context*

Term	**Context**
Industrialisation	Term incorporating manufacturing processes but also including general concepts such as scheduling, efficiency and technology improvements (Blismas, 2007).
Industrialised Building Systems (IBS)	Term formally defined in Malaysia in the early 2000's encompassing the use of prefabricated, offsite, mass produced and standardised components (Yunus & Yang, 2011).
Industrialised housing Industrialised building	Prominently used in Sweden and other European countries since the early 2000's incorporating offsite manufacturing of materials, supplier coordination, and the systematisation of build processes (Lessing, Stehn, & Ekholm, 2005). Historically used in the 1970s and 80s in New Zealand (Bell, 2009).
Industrialised homebuilding	Used in the United States to refer to both modular and manufactured housing as a group (Nahmens & Bindroo, 2011). These two modes are both manufactured off-site, but differ in terms of the building codes that are relevant. See later discussion.
Kit homes Kitset homes Flat-pack kit homes	Set of partially prefabricated materials commonly assembled by an owner instead of a builder, with a particular history of use in New Zealand, Australia and the U.S. (Bell, 2009; Cooke & Friedman, 2001).
Manufactured homes/housing	Used in the U.S. since the 1976 introduction of the alternative Housing and Urban Development (HUD) building code to refer to relocatable, typically low-quality homes built in a factory including an integral chassis for transporting the structure on wheels (Genz, 2001; Manufactured Housing Institute, 2012; Quale, 2006). Used in Australia to refer to houses built in a factory, inconsistently covering both temporary structures installed in caravan parks and villages (Mowbray & Stubbs, 1996) and permanent dwellings installed on standard building sites (Westbuilt Group, 2012).
Modern Methods of Construction (MMC)	Term first used in the United Kingdom to describe changes to improve social housing construction methods (The Housing Corporation, 2003), which refers to both offsite work and onsite efficiency improvements (Goodier & Gibb, 2007).
Modular building Modular construction Modular houses/homes	Used widely including in the U.K. (Gibb & Pendlebury, 2007), Australia and North America (Canada, 2012; Manufactured Housing Institute National Communities Council, 2013) to refer to volumetric elements constructed offsite and joined together to form a permanent house. Specifically distinguished in the U.S. from manufactured housing which has its own building code, while modular building happens under the standard state building codes.
Offsite Manufacture Offsite Manufacturing	Used widely, including in the U.K. and in Australia as part of construction policy documents, referring to work carried out away from the building site (Blismas, 2007; Gibb & Pendlebury, 2007;

(OSM)	Hampson & Brandon, 2004).
Offsite Construction (OSC) Offsite Production (OSP) Offsite Fabrication (OSF)	Interchangeable terms with offsite manufacturing used in multiple contexts (Gibb & Pendlebury, 2007).
Prefabrication Prefabricated	Widely used term with varying interpretations usually referring to offsite manufacturing of buildings, or parts thereof, prior to installation or assembly onsite (Bell, 2009; Gibb & Pendlebury, 2007).
Preassembly	Less commonly used term interchangeable with offsite manufacture and variations (Gibb & Pendlebury, 2007).
Relocatable homes/houses Transportable homes/houses	Terms commonly used in Australia and New Zealand to refer to houses completely prefabricated offsite and delivered to site fully finished (Bell, 2009).

Despite long-standing knowledge regarding the potential environmental and productivity benefits, there has been a low rate of adoption of prefabrication in many housing markets internationally. There is a notion that the housing industry is a ‘law unto itself’ in that it has not universally progressed to mass production such as has occurred for other modern industries like vehicle manufacturing (Barlow & Ozaki, 2005). Anecdotal evidence has been frequently applied to understanding the issues associated with the uptake of prefabrication (Blismas, Pasquire, & Gibb, 2006). Such work has often been specific to particular contexts, ignored broader influences on the housing industry, and lacked clear theoretical direction that could drive further research or policy development.

The current paper aims to address these shortfalls by undertaking a systematic review of the published academic and industry literature on the uptake of prefabrication in housing internationally since the 1990s when it began to be touted in the literature as a way to advance building practices (Gann & Senker, 1993). A theoretical model, based on the previous work of Gann and Salter (2000) is applied to provide structure and to extend the discussion of the determinants of prefabrication adoption. The approach adopted is broad in its scope and conceptually driven, yielding deeper insights than existing literature.

The research is specifically focused on the permanent residential housing market, comprising detached houses, townhouses and apartment blocks. Temporary housing, such as that utilised for remote mining sites or temporary villages is not considered; nor is mobile housing such as caravans and trailer homes. These sectors have better adoption rates compared to the permanent sector (Aburas, 2011). The study also required a clear definition of the innovation under study. A number of categorisations of prefabrication have been suggested, typically describing a continuum from houses completed offsite and placed onsite to the use of lower-order components, as shown in Table 1.

Table 2. *Continuum of prefabricated house construction methods*

Prefab. level	Type	Definition
High	**Complete**	Box-form, volumetric, completed buildings delivered to a building site
	Modular	Structural, volumetric, potentially fitted-out units delivered to site and joined together
	Pods	Volumetric pre-assembly. Fully fitted-out units connected to an existing structural frame such as bathroom or kitchen pods
	Panels	Structural, non-volumetric frame elements which can be used to create space, such as Structural Insulated Panels (SIPs), precast concrete panels and structural wooden panels
	Component sub-assembly	Precut, preassembled components such as doors, and trusses not feasible to produce on site
Low	**Materials**	Standard building materials used in onsite construction

Sources: (Bell, 2010; Gibb & Isack, 2003)

In this paper prefabrication refers to all the categories shown in Table 2, except for component sub-assembly and materials. The research therefore covers structural building panels, pods, modular units and completely prefabricated buildings. Smaller, non-structural prefabricated elements such as pre-assembled trusses are not considered within the scope of the current research as they are highly represented in traditional building and are unlikely to promote the same advantages as more complex prefabricated elements or houses. A further category of ‘hybrid construction’ is also considered in the current study, referring to the use of traditional materials or components in combination with the application of complex prefabricated components (Arif, Bendi, Sawhney, & Iyer, 2012; Bell, 2010).

Theoretical context

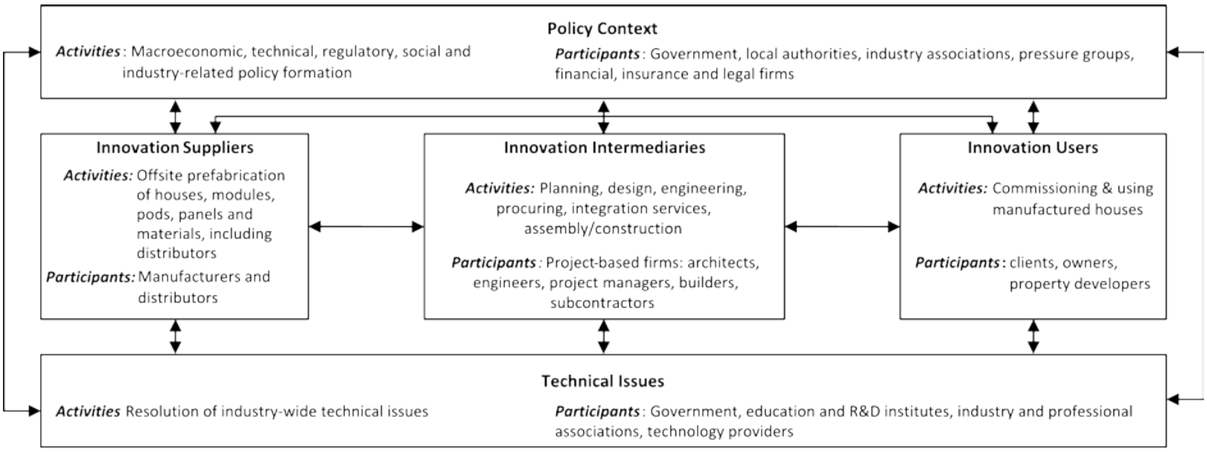
The current review was conducted applying a structured theoretical framework. The study sees prefabricated housing as the result of an ‘open innovation system’ (Chesbrough & Appleyard, 2007). This approach provides an understanding of the broad influences which could impact uptake. This conceptualisation of prefabricated housing as an industrial system involving interactions between many stakeholders and influencers has not previously been addressed in the literature. Gann and Salter’s (2000) Project-based Product Framework provides a structure for examining an ‘open innovation system.’ The framework has been previously applied to understanding topics such as the construction market generally, building supplier issues and methods for ensuring the strategic procurement of sustainable buildings (Erbil, Acar, & Akinciturk, 2010; Marceau et al., 1999; Vogelius, Haugbølle, & Olsen, 2011). According to the framework, the key characteristics that describe the construction industry are:

- the organisation of design and production through projects
- the production of one-off, or highly customised products
- the need for inter-organisational cooperation to deliver projects

This description applies to the housing industry, with the construction of housing being conceptualised as a stand-alone project; the resulting house typically being customised to meet end-user demands; and a supply chain of related but separate stakeholders all having input into the process. The current project adds to this view by conceptualising the housing industry as an open system involving multiple interacting parties, affecting innovation by the degree to which they are open to sharing ideas, knowledge and innovations (Chesbrough & Appleyard, 2007). Within this conceptualisation, it is assumed that increased openness and cooperation between actors leads to increased innovation.

According to Gann and Salter (2000), overall effectiveness of an innovation system is a function of the entire network's effectiveness at working together, rather than the performance of an individual business. Rothwell (1994), in defining fifth generation innovation as lean innovation, states that modern innovations are driven by the need to adapt quickly to address emerging challenges. Modern innovation draws on networks of actors rather than being driven by an individual. There is also a need to envisage building companies, suppliers, regulatory bodies and end-users not as individual actors working in isolation (or in 'silos'), but rather as partners in a larger network working towards a common goal (Da Silveira, Borenstein, & Fogliatto, 2001; Gassmann, 2006; Zainul Abidin, 2010). There is a need to have a holistic consideration of the benefits and disadvantages of using prefabricated housing, from practical builder-level implementation issues, to 'soft' concerns such as health and safety, management and process issues (Blismas et al., 2006). The current paper considers the barriers and drivers impacting the uptake of prefabricated housing from multiple perspectives in line with this systems conceptualisation.

Prefabrication is a radical innovation within the housing system because the dominant methods for completing a project are entirely restructured. As Slaughter (1998) notes: "*all previous linkages and interactions may be irrelevant for a radical innovation, not only with respect to the systems, but also the ties among organisations*" (p227). It is thus worth examining a broad range of influences, even if they are currently not central considerations within the industry. Aside from the immediate interactions between businesses, consideration of the greater context in which an innovation occurs should also be taken into account. Considering socio-political issues and how they may act on the construction industry and related industries is a core part of understanding the drivers and barriers influencing the uptake of any innovation (Goulding, Rahimian, Arif, & Sharp, 2012). The house-building industry does not exist in a vacuum and is a product of structural influences such as economic conditions, the regulatory framework and cultural factors (Barlow & Ozaki, 2005). There is undue focus given to the economic machinations of individual businesses in construction, with little consideration of the greater context of social or institutional influences (Yunus & Yang, 2011). The current research will consider not only the direct impacts of innovation-specific regulations and context, but also the higher-level context of the overall housing industry and macro-level societal influences. The theoretical model used in the current study is shown in Figure 1.



Source: based on Gann and Salter (2000)

Figure 1. *Prefabricated Housing Innovation System*

The model shown in Figure 1 is an adaptation of Gann and Salter's (2000) Project-Based Product Framework, applied to understanding the influences on prefabricated housing innovations. The model is a network showing the main participants in the innovation system. The model links these participants that influence the adoption of innovation within the system. The research reported here covers both demand and supply-side determinants of behaviour. Suppliers are shown on the left of the figure as the manufacturers or distributors of prefabricated houses, modules, pods or structural insulated panels for intermediaries. This grouping includes participants manufacturing and supplying products directly to intermediaries as well as distributors that have no manufacturing role. The intermediaries consist of participants such as builders, architects and engineers that employ supplies to realise the end product of a prefabricated house. These end products are commissioned by a broad group of users which can extend from individuals purchasing a single home as owner-occupiers to developers ordering a large number of new builds. This linear supply chain involves various feedback loops as shown. For example, user feedback can influence manufacturing processes. Further, the supply chain operates in a context where regulations, relevant institutions and technical issues influence their activities. The policy context consists of higher order contextual influences comprising regulatory, macroeconomic and social influences, relevant government departments, and businesses which devise policy and have a direct effect on the day-to-day operations of the supply chain. These participants include government housing and construction authorities, regulators, banks, insurers, and peak industry associations representing groups such as builders. Technical issues which have an industry-wide effect, and efforts to resolve these issues, are also considered. Participants in this model component include universities, dedicated industry research organisations and industry associations.

The overall aim of the current paper is to systematically summarise the existing published evidence regarding the potential barriers and drivers of prefabricated housing uptake, with an emphasis on placing this evidence within the innovation system theoretical model shown in Figure 1. A number of research questions will be addressed as part of this process, namely:

1. What are the key barriers and drivers for the uptake of prefabricated housing innovations?
2. Is the defined housing innovation system appropriate to describe the influences on the prefabricated housing industry?
3. What components of the housing innovation model have been identified as the most central to understanding the barriers and drivers to the uptake of prefabricated housing?
4. What are the future research directions for understanding the uptake of prefabricated housing?

Method

The literature review was primarily undertaken systematically using on-line searches of the Compendex abstract database, which indexes over 9 million articles from journals, conferences and technical reports in the engineering field, including publications related to construction, the built environment and housing. The scope of the search considered recent research published since 1990 onwards, using the key terms as defined below in Table 3.

Table 3 Key Terms used in the search of literature

Search Stem	**Combination terms**	**No. of Abstracts Retrieved**
manufactured	hous*[1]	1408
prefabricated	home	395
prefab		
pre-fabricated		
prefabrication		
container(ised)		569
off-site		176
offsite		
modern methods of construction		135
MMC		
panel		2666
ready-made		92
pre-built		7
factory built		97
factory-built		
factory assembled		
factory-assembled		
pre-assembl*		9
preassemb*		
modul*		9282
industrialised		51
industrialized		
(structural OR insulated) panel		361
transportable	Immediately followed by	202
relocatable		
movable	hous* OR home	

[1] – The asterisk (*) here refers to a wildcard character, allowing expansion of terms such as hous* to house, houses, housing and other similar terms.

As the search terms were broad, all abstracts or reference details were reviewed for relevance, and full-text copies of articles deemed to be relevant to the topic were sourced where possible. Further relevant references were identified through review of the full articles and their reference lists. Supplementary searches using the above terms on the standard Google web-search and Google Scholar website were undertaken to identify further papers or reports that were either published as journal or conference papers outside of the scope of the Compendex database, or were industry and other non-academic publications. A total of 185 relevant publications were reviewed, comprising journal articles, conference papers, reports or theses.

Each of the 185 references was manually coded by the authors along the following dimensions:

1. Research question: a) innovation determinants; b) activity/participant dominance; c) model appropriateness; d) future research
2. Continuum location: a) material, b) panel, c) pod, d) modular, e) complete
3. Participants and activities: a) suppliers, b) users, c) intermediaries, d) policy context, e) technical issues

The paper analyses each of the research questions in turn, commenting on the five different types of prefabricated housing innovation and the roles of the five participants and activities. The main part of the paper is organised around the determinants of innovation adoption – barriers and drivers. The conclusions cover the other research questions.

Influences on prefabricated housing adoption

The following two sections provide summaries of the barriers and drivers of prefabricated housing uptake identified in the literature review. These are presented under the broad headings of suppliers, intermediaries, users, policy context and technical issues as described in the system model shown in Figure 1.

Barriers to prefabricated housing adoption

The barriers to the uptake of prefabricated housing are presented in the following section, organised by the participants and activities outlined in Figure 1.

Suppliers

In line with the theoretical model being used in the current study, interactions with upstream suppliers of raw materials that form the housing supply chain need to be considered. Academic analysis of the supply-chain structure for prefabricated housing has not been extensively discussed (Voordijk, Meijboom, & de Haan, 2006). Dealing with the increased logistics involved in prefabrication has been noted as a trade-off that could diminish the advantages gained through other process improvements. Co-ordinating the supply chain so that it acts reliably and efficiently, and avoids miscommunication between suppliers, contractors and clients is thus a key requirement of a prefabricated house building system (Goodier & Gibb, 2007; Nadim & Goulding, 2011). Setting up integrated partnerships with suppliers has been suggested, though with these relationships comes substantial risk. Having a limited number of suppliers of key materials in prefabrication methods means that there is a large degree of trust and shared risk between a manufacturer/builder and the supplier in terms of business success (Bildsten, 2011; Blismas, Pendlebury, Gibb, & Pasquire, 2005). If a particular established supplier enters receivership, an individual project or entire chain of businesses could be jeopardised (Gibb & Isack, 2003). The provision of scarce and high-value products such as electrical installations are a particular vulnerability as they are not easily replaced or quickly developed in-house by intermediaries (Bildsten, In press). Hofman et al (2009) specifically identified the following supplier barriers: inflexibility in designing and producing purpose-made materials for intermediaries, the risks of design errors compounding all down-stream construction work, and the need to limit the scope of raw components produced to ensure economies of scale. Suppliers of materials such as structural flooring have resisted engaging in integrated relationships with prefabricated construction intermediaries due to the conflict between the project-based housing output requested and the standardised routines and products they are able to offer (Hofman et al., 2009).

Intermediaries

Intermediaries are the builders, architects, engineers and subcontractors that provide the link between suppliers of prefabricated housing and its users. The key intermediary revealed in the literature is the builder as the main contractor on a project. There are a number of practical and cultural issues which builders see as barriers to adoption. The importance of reducing these barriers is underscored by Friedman and Cammalleri (1993) when they state that "*ultimately, the potential for any building material, product or process to be implemented successfully depends on its ability to gain acceptance from the average builder*" (p209-210). The two core elements affecting an average builders' innovation acceptance were noted as return on investment, and the degree of disruption caused to current roles and processes.

Costs and return on investment

The uncertainty of cost savings as a result of a move to prefabrication has been noted (Aburas, 2011; Elnaas, Ashton, & Gidado, 2009). The main challenges to cost identified in the literature can be broken into the initial investment cost to establish infrastructure, and related on-going revenue issues. The barrier of high investment capital to establish mechanised factories has been identified as a clear problem preventing smaller operators from competing in the prefabricated construction space in both the United Kingdom (Lovell & Smith, 2010) and in Hong Kong (Poon, Ann, & Ng, 2003). Elnaas and colleagues (2009) also argue that the current low availability of established plants producing prefabricated components similarly hampers small companies from building on the prior business risks of others. That is, there is insufficient existing activity to provide a robust stream of learning for potential new adoptees. Additionally, while the traditional, onsite building process allows for the ability to start and stop building at short notice, a wholesale move to prefabrication requires an on-going supply of business to encourage economies of scale, which may not be guaranteed in the housing industry (Lovell & Smith, 2010). A higher material procurement cost, though not necessarily a higher overall cost, is a potential barrier to the use of lower-order prefabricated components such as panels. U.S. and Australian research identified upfront cost increases of 5-10% for the use of SIPs over traditional house builds (Gagnon & Adams, 1999), and 20% for the use of sandwich panels instead of standard steel sheet construction (Gurung & Mahendran, 2002).

Challenge to traditional roles

There is little empirical evidence specifically comparing the costs of prefabricated and traditional house builds. There is however, more information regarding negative *perceptions* of builders towards prefabricated houses. Builders are attached to established building methods and their current identities, roles and responsibilities (Nadim & Goulding, 2011; Smith, 1972). This creates inflexible attitudes and negatively impacts on potential improvements to the industry (Lovell & Smith, 2010). Emotive statements regarding the potential loss of uniqueness in building, and the "abolition of handiwork" have been elicited from traditional tradespersons (Outram, 2005, p11). Indeed, there is a real threat to traditional house building work patterns if automation can be applied to the production process, as this would reduce the need for unskilled or unqualified labour (Dainty & Brooke, 2004; Gann & Senker, 1993). Even without automation, prefabrication relies on increased standardisation to reap economies of scale. Thus builders are already becoming dissatisfied with a work environment that lacks customisation and individuality in the building task (Nahmens & Ikuma, 2011).

Process issues
Concerns have been raised by builders that the prevailing lack of planning, and flexible nature of the current construction industry, could not be realistically moved to standardised prefabricated processes (Nadim & Goulding, 2011). Surveys of builders in the U.S. and Malaysia (Lu, 2009; Sadafi, Zain, & Jamil, 2011) have highlighted problems with prefabricated houses, especially the inability to make changes once the building was installed onsite and limited design options. The disruption to processes in the shift to prefabrication has been noted as having a differentially large effect on smaller building companies who cannot adapt their processes due a lack of capital or corporate knowledge about the new methods (Poon et al., 2003; Zainul Abidin, 2010). Related criticisms of prefabrication are that the process is more complex, more design work is required, the error correction cycle is made longer and build tolerances are lowered. These added complexities may manifest as poor build results for early adopters (Gibb & Isack, 2003)); difficulties in liaising with large numbers of unfamiliar or untrained subcontractors (Roy, Brown, & Gaze, 2003)); or management problems resulting from the conflict between traditional methods and prefabrication methods (Vrijhoef & Koskela, 2000).

Users

Considering the demand for prefabricated housing and the interactions of builders and other construction industry members with end users is central to understanding why uptake of this innovation may be limited. As with the prior discussion of builders' barriers to adoption, it is important to understand the unique perspective of the consumer. As Koklic and Vida (2011, p639) note, "*there is a lot of emotion involved in buying a house. Reason starts later.*" Prefabricated housing in the U.S., Europe, and Australasia carries a stigma of cheap, undesirable housing due to associations with mobile and trailer homes (Genz, 2001), collectivist, state-provided housing (Hall & Vidén, 2005; Kährik & Tammaru, 2010), demountable, institutional buildings (Bell, 2010) and temporary mining 'dongas' (i.e. cheap, low quality, temporary, industrial buildings) (Blismas & Wakefield, 2009; Peetz & Murray, 2008). These are serious historical influences, which even if not directly relevant to the current state of prefabricated construction, reflect poorly on the perceived quality and durability of these methods (Goulding & Arif, 2013; Kempton & Syms, 2009). U.S. research has also highlighted public perceptions about the 'unconventional' people associated with such houses (Beamish, Goss, Atiles, & Kim, 2001), and the potential effect on house value (Hegji & Mitchell, 2000).

Owners do not want their freedom to decorate or modify the design of their home to be curtailed (Friedman & Cammalleri, 1993), with some commentators going so far as to suggest prefabricated houses need to be indistinguishable from traditionally built methods of construction (Gann & Senker, 1993) if consumers are to be enticed by the new methods. There is thus a need to resolve the conflict between providing prefabricated housing, and addressing consumers' desire for unique and flexible housing. It is hard to achieve better consumer acceptance and lower product cost (Bildsten, 2011), because of the need to balance customisability against the need for efficient, standardised products (Jensen, Olofsson, Sandberg, & Malmgren, 2008).

Speculative developers are prominent within many regions such as the U.K. and Australia. A high percentage of the profit from house building in these regions is currently derived from well-resourced developers acquiring land banks, building on that land, and selling the developments to a series of individual home owners. This contributes to a tendency for residential developers to "'get in and out' as quickly as possible" (Shearer, Taygfeld, Coiacetto, Dodson, & Banhalmi-Zakar, 2013, p71). Where house building and land acquisition are closely linked, there is limited advantage to be gained in refining the technical elements of the house-building process to create greater value, as the primary value is in the land itself (Barlow & Ozaki, 2005; Pan & Goodier, 2011; Roy et al., 2003). While the largest developers may be best placed to make a shift to prefabricated housing utilising their existing ability to acquire land and negotiate complex regulations (Roy et al., 2003), they may have little current incentive to do so. The largest benefits of producing sustainable houses are rather to the purchaser of the home who acquires a high-performing, affordable residence (Shearer et al., 2013).

Policy context

This section examines how the policy environment may pose barriers to the uptake of prefabricated housing. This extends beyond consideration of formal laws or government policies, and also considers the influence of pressure groups, local authorities, and the broad economic and social context in which the innovation is introduced.

Government policy and enforcement

While formal government policies or legislation are noted as potentially influential in promoting prefabricated housing, they can be limited by lax enforcement, slow implementation, or the need to consult and coordinate a large number of possibly conflicting regulatory and industry organisations. For example, prefabricated housing has the potential to deliver better thermal performance, yet in Australia the regulations to push this along are modest and consequently there is little evidence of builders maximising the advantages, despite potential for considerable environmental and efficiency gains (Miller, Buys, & Bell, 2012).The role of regulators in maintaining existing standards has also been suggested to inherently limit rapidly changing to new methods (Nadim & Goulding, 2011; Tam, Tam, & Zeng, 2002; Zainul Abidin, 2010). For example, the environmental performance of housing regulation in Australia is currently limited to a token consideration of energy and water efficiency. Housing that has the potential to meet much more stringent and broad ranging sustainability goals (e.g. low life cycle impact, zero waste in construction, very high thermal performance) has to compete with the general market that restricts itself to minimum performance levels prescribed by the government of the day (Miller & Buys, 2012).

Policies advocating strictly for the uptake of prefabrication methods, without due consideration or engagement with the wider industry have also been shown to be unsuccessful in changing practices. In the U.K., government policies aimed at engaging sustainable housing methods, which are in direct competition to traditional building methods, have been 'watered down' as a result of lobbying from industry bodies (Lovell & Smith, 2010). Even with industry support, there is the potential for dedicated projects to be adversely affected by poor prioritisation associated with fragmented public sector decision making, as in a failed U.K. modern methods of construction example project (Stansfield, 2005). At a local level, restrictive housing covenants and land-use regulations can also act as barriers to introducing easily distinguishable prefabricated housing. These restrictions often have strong community support as a means to upholding the traditional image of an area (Beamish et al., 2001).

Overall economic climate

The influence of the overall economic market is also significant. The Australian house building industry has expanded and contracted in line with overall market conditions, which has resulted in redundancies and inefficiencies in both the workforce and the use of materials (Blismas, Wakefield, & Hauser, 2010). The recent global financial crisis (GFC) and slowing housing markets are at odds with conditions that would encourage standardisation and prefabrication such as a boom in construction and constrained resource availability (Gibb, 2001). The housing sector is particularly vulnerable to slow economic growth in certain regions, causing concerns for builders trying to secure income streams (Australian Industry Group, 2008). The high revenue required to establish economies of scale in prefabricated housing operations may leave businesses particularly vulnerable to difficult economic circumstances.

Industry funding models

Existing funding models for house building also have implications for prefabrication adoption. The house construction industry has traditionally not been capital intensive, relying primarily on investment from the end user commissioning the building to finance work. A movement to prefabrication could reverse this requirement. If house-building moves to a factory-based supply model rather than an individual demand model (Nadim & Goulding, 2011), the end users could no longer be relied upon to provide the necessary operating capital. This has particular implications for contexts where the housing market is small or geographically isolated because of the lack of a significant pool of potential investors.

At a more immediate level, the actions and policies of financial institutions, lenders and insurers should also be considered. As a result of no established history of quality, or known estimate of product lifespan, reassurances to lenders that prefabricated houses will last and be attractive to potential buyers are still often needed (Craig, Laing, & Edge, 2000). The unfamiliarity of planners, insurers and certifiers with prefabrication all similarly support the current status quo and reinforce end user uncertainty (Lovell & Smith, 2010). The GFC has further increased lenders' scrutiny of risks, which in turn affects builders that wish to present their construction projects as simple, low-risk, and with short loan durations (Shearer et al., 2013). Different types of prefabricated housing are impacted by variance in the way that the finance sector will release payments for the construction. For example, SIPs panels are viewed as construction materials, and payments are made when these materials are constructed to particular levels of completion (e.g. at lock-up stage). However the payments for a house or housing pod that is constructed in a factory are generally not released until the building is connected to services on the building site or it is difficult to secure finance at all (e.g. Australia's Little Hero prefabricated apartment building in Melbourne) (Boyd, Khalfan, & Maqsood, 2012).

Technical factors

Practical, technical issues may also limit the feasibility of moving the house-building industry from traditional methods to prefabrication.

Design issues and flexibility

There is a conflict between architects' desire to generate unique designs and the technical limitations of using standardised, prefabricated materials (Madigan, 2012). There is the additional 'chicken-and-egg' complication in establishing modular building in that, unlike traditional building components, there is not an existing catalogue of components to use in designs, so designs are not made calling for the use of these components (Bertelsen, 2005). Proving the technical merits and appropriateness of prefabrication against existing standards and regulations is a potentially complicating factor (Gann & Senker, 1993).

Material transport

Although it could be argued that prefabricated materials and transportable houses address issues of repeated travel to sites for contractors, the logistics of transporting heavy or large materials to sites should also be considered (Daly, 2009). In terms of increasing insulation for prefabricated houses, there needs to be a consideration of any additional thickness or weight of the final structure, and how this may affect transportation requirements (Perman, 2011) compared to delivering small subcomponent housing elements. Researchers in India have noted the particular issues associated with moving large housing modules into place in cramped urban environments (Arif, Bendi, et al., 2012).

Information technology

The greater involvement of IT processes in the prefabricated building industry to drive automation and reproducibility raises a number of potential barriers, including the inability of businesses to invest in new IT infrastructure, and the need for interfaces to currently used software. The ability to automate tasks has also been contrasted against the need for flexibility in design and construction, being that automation is frequently equated with standardisation. It has however been conceded by representatives of the house building industry, that automation can be applied effectively to particular housing sections such as kitchens and bathrooms (Nadim & Goulding, 2011). This does however raise questions as to why these complex parts of a house are seen as appropriate for automation, but not a complete house construction process.

Drivers for prefabricated housing adoption

As a rebuttal to the previous section, there are a number of influences which have been noted in the literature as encouraging the uptake of prefabrication.

Suppliers

Prefabricated housing adoption may be improved through greater negotiation between suppliers, builders and users. While an integrated supply chain providing fully-customisable end products would be ideal, the use of even a small set of standardised components configured in various ways would bring a number of benefits. The benefits of standardisation include interchangeability of parts, simplicity of connecting parts, consistent measurements and sizes, and consistent and predictable build or assembly processes (Barlow et al., 2003). If long-term, close relationships can be formed between suppliers and intermediaries, the house manufacturing process has the potential to be made simpler and more efficient through the elimination of much of the contracting process (Gann, 1996). Delays in the delivery of housing components is a key cause of inefficiency within the building industry, which would be substantially addressed through the formation of responsive and reliable supply-chain relationships (Lessing et al., 2005). Sharing of technical information through clearly outlined specifications, which are again facilitated in a prefabricated as opposed to traditional-build setting, can ease these problems (Roy et al., 2003). While this may require substantial prior relationship negotiation, it has been found to work in practice in a Swedish industrialised house building business. A simple and efficient delivery of finished housing is facilitated by applying well-specified, tested and standardised housing products through an internally-managed network of long-term contractors and suppliers (Björnfot & Sardén, 2006).

Intermediaries

There are a number of clear benefits to builders and the building process which have been noted in the literature on prefabrication, typically from first-hand feedback from those in the industry. These surveys thus provide a set of factors that could be targeted to achieve greater uptake of prefabricated housing innovations.

Costs and value for money

In line with increased costs being a barrier to uptake, the potential for prefabrication methods to reduce costs and cost uncertainty may be a clear driver for uptake (Nadim & Goulding, 2011). Waste is eliminated through prefabrication's reducing of 'wet' trades and finishing works (Poon et al., 2003), scrap off-cuts, weather damage and onsite material mishandling (Dainty & Brooke, 2004). Recent studies have shown SIPs panels can reduce overall construction costs by 50% compared to brick veneer construction (Miller, 2010) and labour costs specifically by 35% compared to traditional timber framing (BASF, 2007). SIPs' consistent and standardised forms reduce construction effort, the requirement for skilled contractor involvement and the level of waste produced (Miller, 2010; Mullens & Arif, 2006). Together these findings suggest that cost concerns may be perceptual rather than real, with 'systems thinking' not applied to equally weight labour and material costs. This leads to overestimation of costs and underestimation of savings (Harvey, 2008).

The increases in labour efficiency and associated decreases in onsite time, which expose the project to the weather and potential vandalism, have been frequently raised as benefits of prefabrication in surveys of builders' attitudes. Other benefits include the greater quality and higher levels of precision allowed with factory built or automated housing (Bildsten, 2011; Elnaas et al., 2009; Gibb & Isack, 2003; Jaillon & Poon, 2010; Lu, 2009). In particular, the ability to inspect materials as they leave the factory and a finer-grained control over the entire quality assurance process have been noted as off-setting the potentially greater costs of the method (Bildsten, 2011; Gibb & Isack, 2003). Evidence from Sweden has indicated a lower level of defects in industrialised timber houses in comparison to site-built homes in Sweden (Johnsson & Meiling, 2009). The total cost increases may also not be as marked dependent on the time of measurement, with Pan and Sidwell (2011) identifying savings of up to 25% as a builder moves from their first use of prefabricated products to more regular use.

As mentioned by Pan and Goodier (2011), it is not enough however to solely consider the greater process efficiency or quality improvements that can be created as a result of using prefabrication methods. A business model needs to be established early, which considers the needs of the market, the feasibility of utilising the method, and design of how the method meets the needs of the market. These higher level discussions are the key point at which the new methods, even those representing only minor changes to the traditional methods, should be integrated into business' overall plans (Lessing et al., 2005; Pan, Gibb, & Dainty, 2012).

Workforce drivers

The existing house building workforce has the ability to become qualified to produce prefabricated houses given their existing skills (Daly, 2009). Centralising construction activities to an offsite factory would also have the potential to increase their continuity and stability of employment (Goulding et al., 2012). The opportunity for greater process control and repetition of tasks in prefabricated housing also contributes to greater workplace health and safety outcomes by reducing exposure to heights and weather and hazardous tasks such as cutting (Luo, Riley, & Horman, 2005). Whether safety in the workplace would be a primary driver, or one that would be mediated by other factors remains an issue to be addressed.

Builders may not be willing to change from their traditional roles despite these known advantages. The use of less disruptive prefabrication innovations may thus serve to encourage the transition of traditional contractors. The conflict that a prefabrication innovation may generate is directly proportional to the number of trades that it either encompasses or makes redundant. For example, shifting the placement of a window in a traditional house has much less potential for disruption compared to adapting to a completely new wall panel system, unless that wall system has a similar level of flexibility so that a significant level of trade involvement is still required (Friedman & Cammalleri, 1993). The higher level of trade involvement may appeal to those more traditional builders.

Users

For almost any product, end users would wish to be provided with high quality products at low costs, with the housing market being no exception (Blismas et al., 2010). However, it will take the housing industry some time to reach the point that these expectations can be met. The required level of consumer demand to generate a mature prefabricated housing industry is unresolved (Zainul Abidin, 2010).

Costs

Users want an affordable price and a turnkey contract that covers the entire cost of the house-construction without hidden or extended charges (Beamish et al., 2001; Eleb, 2004). This aligns well with the high budget-certainty ascribed to prefabricated housing projects. A willingness to pay among consumers has also been cited as a potential driver of innovation among builders and developers (Zainul Abidin, 2010). If prefabricated homes of a quality comparable to traditionally built homes can be delivered at a lower price point, then this would drive demand, though the reduction in price required to offset any trepidation end users may have is not well established (Madigan, 2012).

Increased flexibility in building

The stigma associated with fully prefabricated houses could be side-stepped through the use of panellised methods of construction. With these methods largely assembled on site and allowing greater design flexibility, they may not appear to consumers as markedly different from traditional building methods (Friedman & Cammalleri, 1993). A unique benefit of using panel systems is the ability to consider open-systems thinking, where a house may be flexible and re-configurable post-occupation (Luo et al., 2005). This has been previously realised by innovative Japanese housing companies who use an overall concrete panel frame with large open internal spaces that can be separated by installed wall panels (Blismas et al., 2010). Similarly, the Netherlands government has recently trialled an Industrial, Flexible, Demountable (IFD) housing initiative. These houses are built using industrial methods and are flexible in their initial design, post-occupation design, and ability to be relocated to a new site. Case studies have shown substantial flexibility in configuration of these houses, particularly when combined with detailed instructional information provided to home owners (Geraedts, Cuperus, & Shing, 2011). Speculative developers have also attracted criticism for commissioning traditionally built houses that are limited to a small number of standardised designs, while also bemoaning that consumers demand absolute flexibility (Pan & Goodier, 2011). This suggests that addressing the expectations of consumers through education and comparing the modern realities of traditional and prefabricated houses may serve an important purpose.

Policy context

There are a number of particularly strong actions that can be taken at a macro-level to support the prefabricated housing industry.

Financial incentives

Financial incentives, particularly those enshrined in legislation, have been shown to be supported and successful in encouraging greater use of prefabrication in housing in south-east Asian countries (Aburas, 2011; Jaillon & Poon, 2010). These incentives comprised exemptions on gross floor area calculations and associated building fees for the use of prefabricated materials in Hong Kong (Jaillon & Poon, 2010) and tax concessions on capital invested in factory equipment in Malaysia (Din et al., 2012). The incentives offered in Hong Kong have particularly encouraged private builders to increase prefabrication adoption (Jaillon & Poon, 2009), while the Malaysian legislation has been flagged as a key promotional tool for countries where prefabrication is not yet prevalent (Aburas, 2011). These incentives do however risk favouring a small number of large companies that are more capable of adapting their work processes without sacrificing the low profit margins inherent in the building industry (Chiang, Hon-Wan Chan, & Ka-Leung Lok, 2006; Din et al., 2012).

Assessment of buildings

Sustainability legislation, policy or enforced construction contract terms can encourage prefabrication. Enforcing sustainability standards around insulation and sound resistance, and actively assessing performance, can strongly incentivise the repeatable, consistent work that is produced through prefabrication methods (Gaze, Ross, Nolan, Novakovic, & Cartwright, 2007; Tam et al., 2002). Prefabrication has been encouraged indirectly in Singapore by requiring builders to meet a minimum score for 'buildability' as measured against the 3S Principles of Standardisation, Simplicity and Single integrated elements. Each of these explicitly favour the use of prefabricated building methods by mandating repetitive sizes and materials, uncomplicated construction and the use of integrated offsite made materials (Chiang et al., 2006). Turner and Vaughan (2012) go so far as to suggest that building codes should be established that are currently out of the reach of most builders to encourage further innovation.

Promotion and example projects
There is also a potential role for governments and industry bodies in developing demonstration projects or technology previews. Presenting physical, real world results through the use of display homes and successful examples could serve to provide a greater impetus to move to prefabricated housing innovations (Gaze et al., 2007; Lovell, 2007). Investing in such projects would introduce builders to prefabrication methods in a low-risk environment, and provide a chance to publicise the results to consumers (Gaze et al., 2007). Additionally, experimentation with new materials and methods would be encouraged (Turner & Vaughan, 2012). Without the explicit provision of funding support, government and industry bodies can still subtly influence the market. One such example is the use of the phrase 'Modern Methods of Construction' in preference to 'prefabricated' in the U.K. which has aimed to avoid some of the stigma associated with the term (Lovell & Smith, 2010). Turning these preconceptions around to a positive focus and a fair comparison to the existing market may serve to enhance the position of prefabricated housing.

Outside of government influences, there may also be a role for industry organisations. There are a number of lobby groups that directly support and encourage the increased use of prefabricated building products, such as the Manufactured Housing Institute in the US, PrefabNZ in New Zealand (Bell, 2010) and the recent creation of prefabAUS in Australia (prefabAus, 2013). Greater education of industry and consumers regarding the benefits of prefabrication, along with a greater emphasis in university or technical education programs could assist in driving its use (Aburas, 2011).

House financing
The prior barriers section reported on the difficulties associated with financing prefabricated house builds. Manufactured house retailers in the United States have addressed this issue by negotiating direct and mutually-beneficial business relationships with lending institutions (Manufactured Housing Institute, 2012). Those financers willing to take the risk of engaging with an emerging prefabrication industry may also benefit from establishing themselves as a monopoly provider of services.

Contextual influences
Significant events, or the interaction of a number of events, can drive sudden change, such as in the United Kingdom where the end of World War II combined with the destruction of houses and a surplus of structural materials encouraged a boom in prefabricated, quick-to-assemble housing (Lovell, 2007). While this issue has not been explored in depth, Luo et al (2005) identified a number of external factors recently impacting on the U.S. construction market that could drive the uptake of prefabricated housing, including rising labour costs, market trends towards higher quality or tighter timeliness, a greater use of technologies and construction management software (e.g. Building Information Modelling or BIM), and a growing focus on green values and sustainability.

Technical factors

Information technology adoption

Prefabricated housing has the ability to reap the benefits of automation. As information technology investment and knowledge increases, so too does the possibility of reducing traditional methods of work (Eastman, Teicholz, Sacks, & Liston, 2011). While the majority of the existing housing construction industry does not have the capability to consider automating tasks, prefabricated builders are comparatively better-placed to do so as a result of a greater opportunity to employ standardised materials. The integration of Building Information Modelling to model the construction process could aid substantially in the ability to adapt to automation (Neelamkavil, 2009), through the establishment of standardised, data formats that can adapt to differing projects (Nawari, 2012). As such, it has been recognised as a high priority in the short-term for encouraging greater use of prefabrication (Goulding et al., 2012).

There is also benefit to be gained from having standardised, data-based descriptions of projects that can be simply recalled for re-use (Lessing et al., 2005; Sandberg, Johnsson, & Larsson, 2008). Agreeing upon open specifications for particular products such as structural panels would encourage interoperability, and drive industry-wide competition and innovation (Blismas et al., 2010), while continual adaptation to and updating of competing standards could hamper the development of economies of scale (Craig et al., 2000). Engagement with architects and designers to consider building designs that use standardised components would additionally support this movement (Aburas, 2011). There would not necessarily be a need to immediately adopt highly automated or mechanised building processes to begin to reap advantages such as the centralised production lines and parallel workflows associated with factory built housing. Case studies of the U.S. manufactured housing industry have highlighted these benefits even with the substantial continuation of traditional labour-intensive work within factory-based settings (Senghore, Hastak, Abdelhamid, AbuHammad, & Syal, 2004).

Conclusion

The current paper has systematically reviewed the published evidence regarding the barriers and drivers for the use of prefabricated housing. In addressing Research Question 1, a number of key barriers and drivers have been identified. For suppliers the key issue is the ability to form integrated and mutually beneficial relationships with intermediaries using their products, encompassing sharing of knowledge, development of standardised products and negotiation of the co-dependence of business risk. The primary issues for builders as the key intermediary appear to be resistance to change for a variety of valid reasons including the business risk associated with process changes and threats to livelihood and revenue. These threats appears to be particularly pertinent for smaller businesses because they have fewer resources to support the adaptation process. Opposing these threats are the potential improvements in operating costs, efficiency and quality which may await those businesses that are successfully able to embrace new methods.

Negative consumer perceptions are a significant barrier to developing a large market for prefabricated housing, even if some of these perceptions are not representative of the emerging industry. Again, reducing the end cost of purchasing houses has been identified as a major identified driver that can cut through potential misconceptions. Reshaping the market to discourage the short-term profit model of speculative developers would also encourage further investment in prefabrication technologies.

The definitive set of regulations and contextual influences which are relevant to the prefabricated housing industry are unclear from the available evidence. This appears to reflect both a lack of regulation specifically concerning prefabricated housing as well as a lack of research specifically assessing regulations that have been instated. In line with builders' focus on cost issues, economic drivers such as offering tax concessions appear to be key immediate influences, while there is some limited indication that softer methods aimed at instigating a cultural shift may also be effective. In terms of technical support issues, integration of designs with information technology processes such as BIM embody both the most critical barriers and drivers.

The above discussion identifies the key determinants of innovation adoption within each component of the Prefabricated Housing Innovation System. The current results thus support Research Question 2, in that a diverse range of influences were able to be categorised and explored using the model in Figure 1. Research Question 3 was addressed by identifying the components of the system that are most central to understanding adoption decisions. The clearest research findings in the current study concerned immediate influences on the industry, such as the process and financial cost influences for the builders that are directly involved in the physical construction of houses. There was less direct evidence concerning some of the more distant influences such as regulations, consumer sentiment and cooperation between suppliers and building intermediaries. The system approach thus draws attention to under-researched areas that impact on adoption rates. The current study adds to previous work in the field by taking a broader approach. Existing research reflects the relative ease and familiarity of housing researchers in measuring immediate outcomes. In that sense, while these immediate considerations are currently the most discussed and central issues, they should not necessarily remain so.

In answering Research Question 4, the following discussion outlines a number of future research directions.

Understanding industry transition

The restructuring of traditional builder and supplier methods of working, both independently and together, highlights the need to further understand *how* the house building industry will transition. It might be that the industry will embrace prefabricated housing incrementally. It may not be useful to emphasise the traditional nature of house building, as if the difference between current practice and best practice is too great, the industry may hesitate over the first steps to improvement. Similarly, it may not be good to set prefabricated housing up as competition to tried and tested traditional methods, as this may create the impression of unacceptable risk (Gann, 1996). Further investigation is required into how disruptive or easily taken-up particular innovations are, rather than broadly considering prefabricated and traditional build methods as irreconcilable, polar opposites (Friedman & Cammalleri, 1993; Roy et al., 2003). Further knowledge is also needed regarding possible management approaches to allay the impact of the changes to working arrangements in a prefabricated housing setting, and achieve greater efficiency (Arif, Goulding, & Rahimian, 2012). Subtle differences in perceptions towards prefabrication are likely dependent on specific contractor roles. While architects have reported a negative perception of the reduction in design time associated with prefabrication, that was disparate to engineer and builder perspectives; engineers have uniquely prioritised the inflexibility of prefabrication techniques. (Jaillon & Poon, 2010). The differential impact of innovations across groups should be examined and self-serving opinions should be differentiated from best practice.

Costing data

Further empirical evidence is required into the costings of specific prefabricated housing innovations. Cherry-picked costing figures in isolation do not adequately represent the benefits and costs of varying construction methods. For example, a study of bespoke detached housing in sub-tropical Australia found that the total cost of designing and constructing a house can be difficult to determine for comparative purposes because costs are incurred at various stages of design and construction, are payable to multiple supply chain agents, and there is no common standard for determining the scope of which costs are included in a recognised house price (Miller et al., 2012). Rather, these comparisons would benefit from detailed costings separated in a logical manner including the costs of physical materials, labour costs, costs due to delays; or from a planning perspective, the certainty of costs at the time of contract signing, and the variability of costs during the build process (Gibb, 2001).

Consumer focus

More effort and research is required to specifically understand the perspective of consumers regarding prefabricated housing (Lessing et al., 2005). It has been argued that there has been an undue focus on the build process, rather than on determining how best to meet consumer demands using prefabrication methods (Madigan, 2012). It is largely unknown to what degree the house-purchasing public will accept limitations on the flexibility of housing designs as a trade-off against the potential benefits (Nahmens & Ikuma, 2011; Pan, Dainty, & Gibb, 2012). Further, more sophisticated examination of costs beyond the purchase price is required, to consider certainty of costs, maintenance costs and living expenses post-occupation (Eleb, 2004). Indeed, what constitutes value for a consumer, such as low whole-of-life cost and design input, may differ substantially from a builders' emphasis on efficiency and profitability (Björnfot & Sardén, 2006). There exists little evidence however elucidating these factors and their influence. Further understanding of the market segments where prefabrication would be likely to have the greatest take-up is also needed (Bell, 2010). The viability of prefabricatoin companies has been noted as being strengthened by being able to target particular segments of the market, such as low-cost housing, extensions, remote housing, or even the export market (Bell, 2010; Jensen et al., 2008). Each of these segments would however have their own set of challenges in terms of legal, social and economic influences which would need to be outlined and researched.

Understanding contextual influences

There is a continuing need for clearly defined, rigorous research to determine the value, from multiple perspectives, of adopting prefabrication, rather than a reliance on anecdotal evidence or consideration of only narrow outcomes such as immediate costs. While costs were noted in this review as a central consideration from a builders' perspective, Blismas et al (2006) suggest there is an undue emphasis on this aspect, in detriment to the consideration of non-monetary implications of a change to using prefabrication. Goulding et al (2012) outlined a number of future challenges and opportunities that should be research priorities including understanding socio-economic drivers, integrating the design community into the new processes, addressing the skills shortages across the construction and manufacturing sectors, addressing the needs and expectations of end-users, and considering how prefabrication processes work alongside existing or future standards and legislation (Goulding et al., 2012). Well-designed research is required to make valid one-to-one comparisons between prefabricated and traditional house-building methods which acknowledge their inherent differences and differing contextual influences (Pan, Dainty, et al., 2012). The ability to measure progress in shifting to prefabrication is also key. Without clearly defined assessment tools that target observable and measurable outcomes, there is unlikely to be clear guidance on the future of the housing construction industry (Yunus & Yang, 2011). One area to watch is the growing research examining the influence of Building Information Modelling on the future of the housing industry (Eastman et al., 2011; Succar, 2009). Given its strong relationship to prefabrication, there should be further exploration of how best it could interface with a movement to prefabrication.

Among these various strands of proposed future research, the authors intend to undertake an in-depth examination of the determinants of adoption from builders' perspectives. This component of the Prefabricated Housing Innovation System will be analysed in the context of broader system influences on their behaviour. This research will fill a gap in the literature where up until now this holistic perspective has been lacking.

The greater application of prefabricated as opposed to traditional house building methods has been acknowledged as having a number of potential advantages in terms of efficiency and reduced environmental impacts, and understanding the current influences on its uptake is thus an important undertaking. The housing innovation system as described in this paper has been successfully applied to gain a greater understanding of these interacting influences. It has allowed the identification of key influences and commonalities in the existing published research, and provides a structure that can be easily be adapted or expanded upon by future researchers.

In summary, this paper has advanced the frontiers of knowledge around manufactured housing by:

1. Identifying the evidence of key barriers and drivers for adoption
2. Showing that the Prefabricated Housing Innovation System provides a useful organising principle to describe the influences on growth
3. Identifying the components of the housing innovation model that are most central to understanding the barriers and drivers to adoption
4. Identifying future research directions for understanding adoption decisions

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