Barriers and enablers for supply chain integration in prefabricated elements manufacturing in New Zealand

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ABSTRACT

The attention on prefabricated modules and components is resurging in the New Zealand residential construction industry. This is driven by its relative benefits and technological advancements. However inspite of this attention, there has not been commensurate understanding of its manufacturing supply chain and the enhancement of their performance. Similarly, there has been little research considering the supply chain and supply chain integration in module/component manufacturing in residential construction in New Zealand. Therefore, this paper presents a comprehensive overview of the modular manufacturing process and the barriers and enablers for supply chain integration in module manufacturing. The identified barriers are discussed with their relevant enablers. Information for the study investigation was collected through twelve semi-structured face to face interviews with prefabrication experts. The information obtained was analysed using content analysis that enabled the development of a framework that illustrates barriers and enablers for supply chain integration. Ad-hoc relationships, poor planning and scheduling, transporting of volumetric modules and information sharing are a few significant barriers in the manufacturing process of modular bathroom pods and wall panels in New Zealand. The proposed framework provides a guide for the wall panel and bathroom pods manufacturing companies to improve integration across their entire manufacturing process.

KEYWORDS: Housing, Prefabrication, Modular pref0abrication, Supply chain, New Zealand.

INTRODUCTION

Prefabrication has long been reported as an effective alternative to conventional construction, with wide-ranging benefits. It serves as a valuable source for providing time, cost, quality, productivity, health and safety and environmental benefits to construction. Concerning these facts, studies have been carried out to explore the benefits of prefabrication (Lawson & Ogden, 2010; Pan, Gibb & Dainty, 2012; Pasquire & Gibb, 2002), improving of the prefabrication supply chain (Doran & Giannakis, 2011; London & Kenley, 2001; Naim & Barlow, 2003; Stroebele & Kiessling, 2017), prefabrication and lean manufacturing (Arbulu & Ballard, 2004), and lately, the integration of supply chain strategies to prefabrication (Lessing, Stehn, & Ekholm, 2015; Mostafa, Chileshe, & Zuo, 2014). However, there has been little research considering the nature and the constraints in the prefabricated housing supply chain.

While countries like UK, US, Japan, Australia, Hongkong, Malaysia, Singapore have realised the benefits of off-site manufacturing techniques in housing construction, New Zealand appears

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to be taking minimal advantage of prefabrication due to inefficiencies in its supply chain (PrefabNZ, 2014). Therefore, this paper attempts to fill the gap by investigating the nature and the barriers of the prefabricated supply chain, specifically in the wall panel and bathroom pods manufacturing for housing construction.

This paper first draws a background picture of the concept of supply chain integration (SCI), prefabricated housing construction and the nature of the New Zealand prefabricated housing sector based on literature. The paper presents the processes and relationship networks of the supply chains in the manufacturing process of prefabricated elements used to construct houses based on data collected through the semi-structured interviews. Further, the paper highlights the barriers and enablers for SCI in the manufacturing process of prefabricated elements and maps theses barriers and enablers against the stages of the manufacturing process.

Construction supply chain integration

Supply chain integration, a concept in supply chain management focusses on achieving a reliable, accurate and timely flow of material, information and finance across the whole network to provide consumers value for money. Integration of the key business functions across the supply chain can provide benefits resulting from the reduction in cost and time taken to produce an order (Power, 2005).

Unlike the manufacturing industry, the one-off product is assembled on the construction site through temporarily set up supply chains (Vrijhoef & Koskela, 2000). The unique nature of the construction supply chains seems to be far from a production standpoint (Fearne & Fowler, 2006). However, Egan (1998) and Dubois and Gadde (2000) recommended integrating the processes and products in the construction sector to achieve value for the client.

Even though supply chain integration offers the potential to improve efficiency and effectiveness, there are barriers linked with implementation. Awad (2010) has identified three perspectives that researchers considered to categorise barriers for SCI. These perspectives include technical, managerial, and relationship, where technical relates to the technical barriers that arise between the SCM systems and strategies; managerial refers to the obstacles that result in planning and execution of strategy and relationship relates to the challenges that affect the relationships within and outside the organisation (Awad, 2010). Similarly, there has been several studies carried out to identify the barriers for supply chain integration in the construction industry (Akintoye, McIntosh & Fitzgerald, 2000; Barratt, 2004; Briscoe & Dainty, 2005; Vrijhoef, Koskela & Howell, 2001). These barriers include lack of senior management commitment, lack of understanding the concept of supply chain management, inadequate organisational structure to support the supply chain management system, low commitment of partners, uncertain strategic benefits, and a lack of appropriate information technologies. Even though the barriers for SCI they were not properly catogorised and addressed considering the nature of the project.

The supply chain of prefabricated houses

A supply chain is classified into two processes like production planning and inventory control and logistic and distribution (Beamon, 1998). A construction supply chain is a network of participants and organisations engaged to a network of relationships and organisations together with the flow of information, the flow of materials, services or products, and the flow of funds between the owner, designer, contarctor, subcontractors, and suppliers (Muya, Price & Thorpe, 1999). Modular Builidng Institute (MBI) has divided the prefabricated housing supply chain into four stages; (i) design approval, (ii) manufacturing of modules/components off-site, (iii) transportation of modules to a destination and (iv) assembly of modular units to form the finished building (MBI, 2010). In prefabricated house building supply chain, different business entities, including manufacturers, suppliers, developers, contractors, and distributors are directly and indirectly engaged to deliver the house to the client/customer (Mostafa *et al*., 2014), processing forward flow of materials and a backward flow of information (Beamon, 1998).

Generally, the supply of prefabricated houses takes place in two phases pre-assembly and on-site construction. Both of these have different demands on the supply chain where pre-assembly involves designing, material handling, manufacturing, and transportation to the site and on-site construction includes preparation for installation, foundation and installation (Lessing, 2015; Vrijhoef & Koskela, 1999). In the pre-assembly phase, design and planning stages are critical milestones as it involves-design freezes, cost planning, methods of procurement and project planning and scheduling. As a designer, a thorough understanding of the basic requirements is needed to develop the design for subsequent approvals and to minimise the complications in the construction stage.

Vrijhoef and Koskela (2000) have developed a traditional make-to-order construction supply chain, considering the relationships of the participants of the construction project. A supply chain is developed aligning the information and material flows among the participants through the construction process. Xue *et al* (2005) developed another framework considering the stages of construction from the clients demand to the completion of the project. In this framework, the general contractor is considered as the core of the process and connected to the two main participants; owner and designer. Compared to earlier researches, this includes all the direct and indirect participants and mapped the flow of finance along the supply chain. Johnsson and Meiling (2009) developed a timeframe for a typical industrialised house building project to identify the defects in the process. Several other studies related to the construction supply chain have attempted to explore and develop the network of the supply chain. However, there is little to no research on the integration of supply chains of prefabricated elements

Prefabrication construction is one of the effective alternatives to conventional construction, with diverse benefits (Pan & Sidwell, 2011). Compared to traditional construction, it is one of the innovative and effective methods of delivering sustainable construction (Zhai, Reed, & Mills, 2014). However, the barriers to using this innovative method have limited its wider uptake in the construction industry, specifically in the housing sector.

Traditional drivers of the time, cost, quality, productivity, health and safety, and environmental impact encourage the industry to make more use of prefabrication methods in housing construction compared to their traditional counterpart (Forum, 2002; Sparksman, Groak, Gibb & Neale, 1999). In prefabrication, construction time spent on the project site operations is minimal, and it reflects on evading delays due to disruptions from weather conditions (Waskett, 2003). On average, construction time is reduced by 40% in prefabricated construction compared to traditional construction methods (Lawson & Ogden, 2010).

Prefabrication could yield cost benefits over traditional construction owing to standardisation, automation and energy efficiency. Even though the initial cost of establishing prefabrication is higher than traditional construction, cost savings are possibly achieved through efficiency, learning, innovation, partnering, and in-house build management (Pan & Sidwell, 2011).

The current manufacturing capacity and associated costs inherent in the uptake of prefabrication construction in the housing sector seems to be influenced by the optimisation of production capacity by theses suppliers (Venables, Barlow & Gann, 2004). The low level of partnering between builders and manufacturers and suppliers in housing construction appears to be one of the problematic issues (Pan, Gibb & Dainty, 2008). Thus, to achieve efficiency in cost and design, it is essential to develop and maintain relationships between the builder and the supplier.

Although prefabrication adds value in terms of on-site skill deficiency (Barker, 2003), the requirement for experts in technical aspects remains a problem (Chiang, Chan & Lok, 2006). The craft-based traditional approach to housing construction results in difficulty in process control, and the inability to supply a skilled workforce has worsened the issue (Roy, Low & Waller, 2005). Public perception is another inhibiting barrier that comes along with the adoption of prefabrication in housing construction.

Prefabricated house construction is more likely to be challenging than conventional practices, as is evident from the activities that take place on-site and off-site (Mostafa *et al*., 2014) and therefore requires greater attention in integrating prefabrication into off-site construction (Pan *et al*., 2012). Moreover, prefabrication housing construction has been inhibited by cost barriers, less flexibility in design and negative perceptions (Bildsten, 2011; Goodier & Pan, 2012; Mostafa*et al*., 2014; Pan & Sidwell, 2011). In addition to those, extensive project planning from an early stage, lack of coordination and communication, and transportation constraints are found to be other barriers in prefabricated house building (Kamali & Hewage, 2016; Pan, Gibb & Dainty, 2007). These result in a slower response to the house-building supply chain.

As most of these barriers align with the supply chain of prefabricated house building, Bankvall *et al* (2010) exemplified the necessity to manage and improve the efficiency of the entire supply chain.

Prefabricated housing construction in New Zealand

New Zealand housing construction sector is struggling to achieve the balance between supply and demand with inadequate traditional construction methods (NZPC, 2012; PrefabNZ, 2014). Productivity and quality issues within the industry are creating a more challenging environment for builders (Mbachu *et al*., 2017; PrefabNZ, 2014). Prefabrication has been identified and initiated as one of the promising approaches to overcome issues associated with the housing construction sector (PrefabNZ, 2014). According to the report by PrefabNZ (2014), the usage of prefabrication for non-residential buildings and residential buildings is 11% and 37% respectively. Mainly, prefabricated timber wall panels, roof frames, joinery and windows are used for housing construction in New Zealand (PrefabNZ, 2014).

The residential construction industry in New Zealand is taking minimal advantage of prefabrication due to inefficiencies in its supply chain (Construction, 2011; PrefabNZ, 2014). The concept of supply chain management can mitigate the barriers through active engagement of the members of the supply chain and a clear focus upon the alignment and integration of the processes (Doran & Giannakis, 2011). However, construction supply chain practices are at a tactical level in New Zealand mainly due to high expectations, small economic size and physical isolation of the country (Masood, Lim, & Gonzalez, 2016). The fragmented nature of the New Zealand housing construction sector has increased the potential for coordination problems, development of adversarial relationships, time delays and rework (Basnet *et al*., 2003). This paper, therefore, focuses on identifying barriers and enablers for SCI in prefabricated elements manufacturing and developing a framework by mapping these enablers and barriers to the manufacturing process to provide a guide for the prefab element manufacturers to improve their efficiency in the house building process.

METHODOLOGY

The research aims to identify the barriers and enablers for SCI in the prefabrication element manufacturing process. Therefore, the paper first provides a review of prefabricated housing construction and supply chain integration, barriers and enablers for Supply Chain Integration (SCI) and the current practice of prefabricated housing construction in New Zealand. The literature review streamlines the theoretical aspects against the practical situation on SCI and prefabrication. A literature review is crucial to pinpoint the published work on a particular area and confirm existing knowledge gaps (Fellows & Liu, 2015).

The second section demonstrates the analysed data from the twelve semi-structured interviews. The purpose of conducting semi-structured interviews was to identify the process and the relationships in the supply chains of prefabricated elements used in house building and barriers and enablers for supply chain integration. Industry experts who are engaged in prefabricated housing construction participated in these interviews. All the interviewees were with management-level professionals involved in designing, manufacturing, and constructing prefabricated houses, elements, and modules.

The interviewees were coded from P-01 to P-12, to ensure their privacy. These interviews were conducted through a combination of face-to-face and skype conversations. The following table presents the participant's experience in the industry. Purposive sampling was used as the sampling technique as it facilitates capturing participants, appropriate to the study based on the researcher's knowledge and opinion (Tongco, 2007). Participants were contacted through e-mails and selected considering their expertise in prefabrication, availability and willingness to participate. The final part of the paper covers recommendations and conclusion, developed from the findings.

Among the prefabricated elements, modular bathroom pods and prefabricated wall panels are common choices in New Zealand house building. Further, examining the whole building manufacturing is not realistic as modular homes are not the public choice in New Zealand (PrefabNZ, 2014). The interview questions are developed to capture stages and relationships in supply chain processes of prefabricated elements manufacturing and the barriers and enablers for SCI in the prefabrication. The first part of the interviews focused on the process and the networks of the actual supply chain of prefabricated house building to provide the basics of the New Zealand housing industry. The second part of the interviews highlights the barriers and enablers for SCI in modular bathroom pods and prefabricated wall panels as the second part of the interviews.

Data collected from the interviews were analysed using thematic content analysis. The thematic content analysis focusses on examining themes within the data set. As this paper represents the basic structure of the modular elements manufacturing process, issues in the supply chain, and suggestions to improve the supply chain, the thematic content analysis is the best approach to identify the common themes across the data sets (Fellows & Liu, 2015; Saunders, Lewis & Thornhill, 2009). Based on the thematic content analysis major themes, and sub-themes were identified and finally, the framework was conceptualised.

Table 1: Demographic data of the participants

ID	Role	Relevancy to the NZ residential construction industry	Experience
P-01	Managing Director	Manufacturing ceiling battens and roofing battens, steel frames, steel trusses and steel floor joists	14.5 Years
P-02	Associate Director	Working as a designer/project architect in industrial, commercial, residential and institutional sectors	11 Years
P-03	Managing Director	Design, manufacture and build modular houses	25 Years
P-04	Consultant	Engage in projects on Environmental Sustainability of the residential built environment	10 Years
P-05	Managing Director	Develop affordable modular houses	15 Years
P-06	Director	Develop modular house elements	7 Years
P-07	Chief executive	Residential development	13 Years
P-08	Director	Design, manufacture and build modular houses	8 Years
P-09	Director	Modular construction	3 Years
P-10	Technical Manager	Develop and educate of mass timber market for residential construction	5 Years
P-11	Production Manager and Director	Engage in residential development	7 Years
P-12	Operational Manager	Timber manufacturing for residential construction	14 Years

FINDINGS

The findings section is consisting of four subdivisions including modular bathroom and wall panel manufacturing process, barriers in these processes, solutions to overcoming the barriers and the framework developed based on barriers and enablers in the supply chain of modular elements manufacturing. These four subdivisions were derived from the main themes identified through the data analysis.

Modular Bathroom and wall panel manufacturing processes

The first part of the interview was focused on the current practices of prefabrication in New Zealand residential construction industry. The attention for prefabrication is resurging in the New Zealand housing construction industry driven by its benefits. Although the benefits of prefabrication are widely understood, the adoption level is comparatively low due to initial cost of implementation, lack of skills and experiences, bespoke nature of construction, negative perception towards innovation and complications in the supply chain (NZPC, 2012, PrefabNZ, 2014, Masood, Lim & Gonzalez, 2016). Besides, participants admitted that there is a current trend towards the construction of modular homes and container homes to provide solutions for the crisis of the affordable houses in New Zealand. However, the demand for modular and container homes remain controversial.

As this paper focuses on wall panel and modular bathroom manufacturing, the stages of these two processes were examined during the interviews. The bathroom manufacturing and wall panel manufacturing processes were developed based on the interviews, where interviewees were asked about the stages and relationships in the manufacturing processes. The processes of these two are almost the same except for the production stage. The modular bathroom manufacturing process is shown in Figure 1.

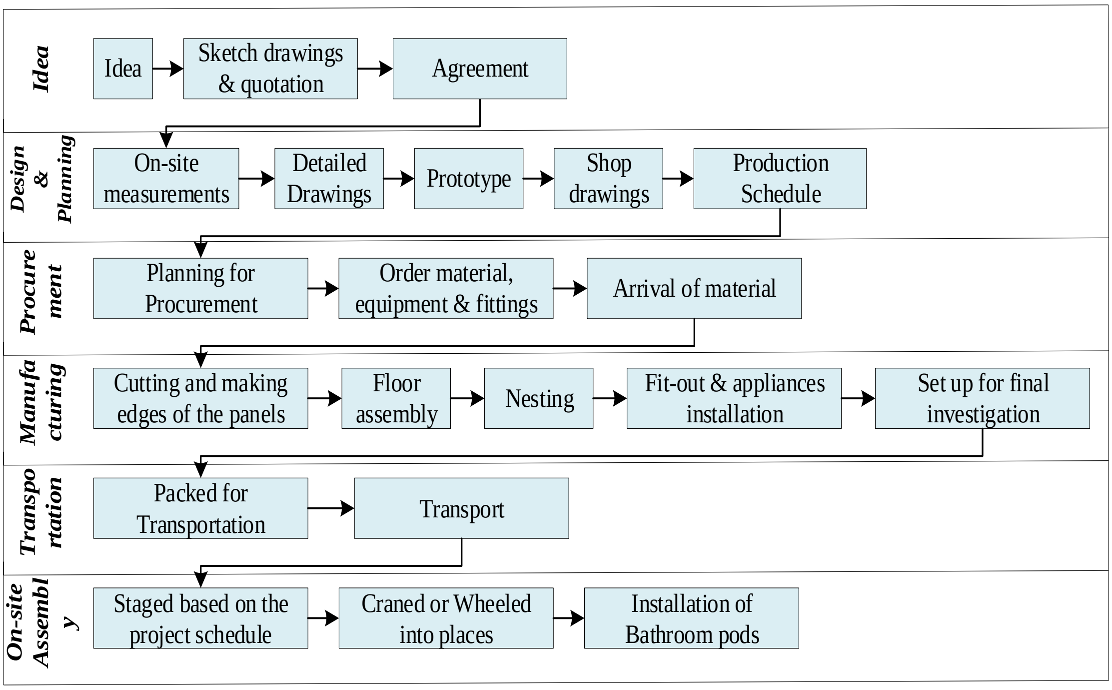

Figure 1: Modular bathroom manufacturing process

Modular bathroom pods are mass-produced under controlled manufacturing conditions and delivered to the project site based on the schedules. These are inherently beneficial in achieving tight deadlines, minimal site impact and are generally used in repetitive structures like apartments. From initial inception to the on-site installation, the manufacturing process of modular bathroom pods is structured. The module manufacturer is the accountable person for these three stages. The process starts with the client's initial requirement and extends to detail design and planning, production and on-site assembly. Designing of the modular pods is a key milestone of the process and it includes taking on-site measurements, sketch designing, detailed designing and preparing shop drawings. Material procurement and handling and delivery of the bathroom pods require greater attention to prevent delays and disruptions in the process. The production process starts from preparing the shell and continues with panels assembly, installation of appliances, and equipment and final decoration and fitment.

The modular bathroom manufacturing process is complex compared to wall panel manufacturing as it involves numerous aspects of design and construction. In New Zealand, most of the wall panel manufacturers procure timber panels from a supplier and produce high-quality customers wall panels like Cross Laminated Timber (CLT) panels. The process starts with the client's initial requirement and extends to designing, planning, procurement, production and on-site assembly (Figure 2). In production, timber panels are cut according to the production drawings and then the workers apply the prime coat to prepare for subsequent edge preparation. Second coat of paint is applied only if it is especially required. In the final stage of production, openings (for doors and windows) are prepared. Finished wall panels are staged based on the installation order in the factory to be delivered to the site.

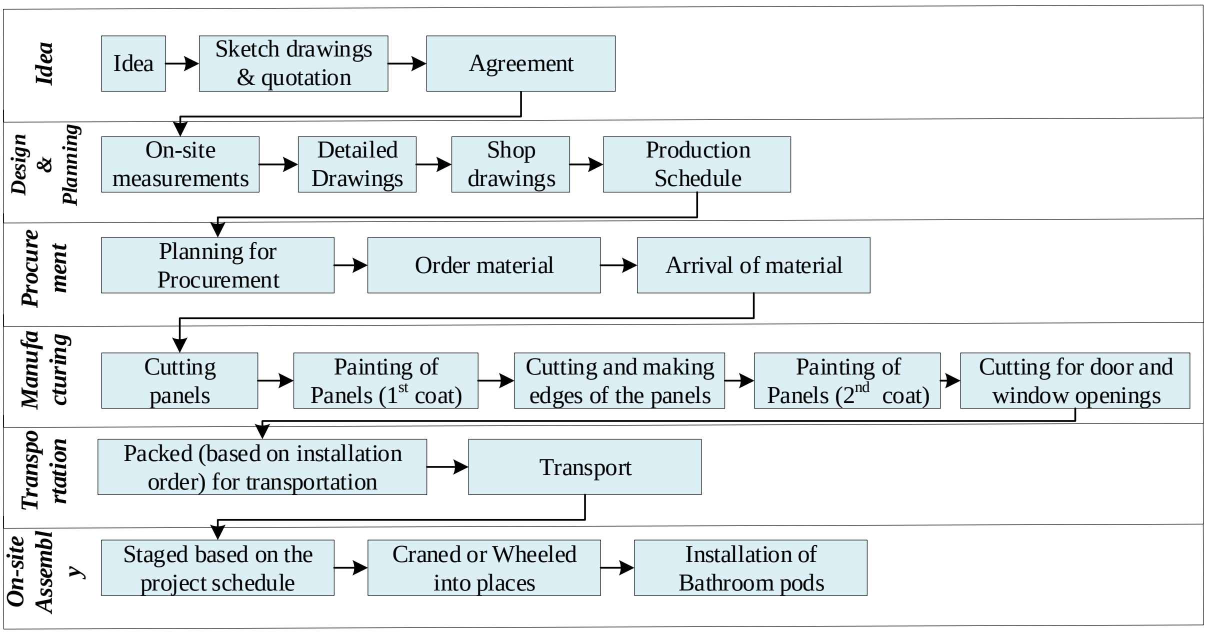

Figure 2: Prefab wall panel manufacturing process

As the processes of modular bathroom pods and wall panel manufacturing are developed, the next step is to identify the barriers associated with the manufacturing processes to improve the efficiency of the production. Therefore, participants were asked about their opinion on barriers in the manufacturing process of prefabricated elements and mitigating these issues by using prefabrication.

Barriers in the supply chain of modular components

The identified barriers in the supply chain of prefabricated elements were classified under four categories as shown in Table 2. The external factors identified are not under the control of the manufacturing companies. Therefore, in this research, only the barriers that can be controlled by the manufacturing organisations (marginal barriers, relationship barriers and technical barriers) are considered.

Compared to traditional construction, prefabrication requires a proper management system from start to end of the production to avoid delays and to achieve customer satisfaction. As noted during the interviews, the lack of project planning and scheduling seems to be a major internal barrier in both manufacturing processes. This is reflected by the statement made one of the interviewees that:- "*when time progresses and the design progresses, it gets harder to change the design, so, we need to plan and schedule the work to minimise barriers, but the problem is that the industry is not focusing on this*" (P-02). Jonsson (2014), Kamali and Hewage (2016), and Jaillon and Poon (2008) also highlighted the essential requirement of having a proper project planning system for prefabrication construction as manufacturing starts before the on-site construction and less flexibility in design changes. However, in New Zealand, most of the prefab manufacturing companies do not seem to be using advanced project planning tools for planning and scheduling. In line with that, Wilkinson (2001) highlighted unrealistic goal setting as a main problem in New Zealand construction projects. Therefore, this coupled with lack of project planning may create delays and disruptions to the manufacturing process. Poor directions and guidance from the top-level managers is another barrier in the production process. According to the participants "*instructions for production are informed by drawings and basic production plans*" (P-11). Production plans for the machine operators are generally developed based on daily or project basis considering the drawings. Therefore, delays are inevitable in case of a variation in the design.

Table 2: Barriers to supply chain integration

Managerial Barriers	Technical Barriers	Relationship Barriers	External barriers
Inadequate project planning and scheduling	Lack of information sharing	Lack of long-term partnerships	The scale of the New Zealand market
Inconsistent goals within the company	Lack of technology and automation	Lack of trust among the stakeholders	Undercapitalised companies
Lack of clear direction and guidance	Transportation of modules		Anti-competitive behaviour
Inadequate performance measurement systems			Lack of education about the benefits of prefabrication
Lack of understanding of SCM			
Lack of knowledge in consumer demand			

Prefabrication is about improving efficiency in construction. However, in New Zealand, most of the manufacturing companies are operated based on a project basis and try to achieve a particular project within the timeframe with less automation. Real-time performance measuring systems are not adopted in their companies. Similarly, the prefab manufacturing industry is not attentive in using manufacturing concepts like SCM, to improve their efficiency. However, one of the participants highlighted the usage of Lean Principles to minimise waste (P-10).

A clear idea of the market demand and its trends is necessary to ensure that the companies are getting sufficient work for survival and growth within the industry. Market investigations and surveys are needed to forecast consumer demand and demand trends in the market. However, among the interviewees, only one company had a database for customer demand evaluation, and most of the other participants regarded as a barrier.

Effective and efficient means of coordination and communication is needed throughout the whole process of delivering a prefabricated building, including project planning, procurement, supply chain scheduling, assembling and construction, and delivery (Kamali & Hewage, 2016). As noted, manufacturing companies are not using any standardised information-sharing systems to share information openly. This is emphasised by one of the statements given by a participant as follows. "*We communicate information through informal ways like word of mouth or e-mails*" (P-03). Generally, e-mails, phone calls, face to face talks, meetings are used to communicate and share information.

Further, the usage of modern technologies for designing and information sharing in the New Zealand construction industry appears to be at a deficient level. According to participants, "*technological barriers in 3D scanning, modelling and 3d dimensioning and that sort of things are quite new in New Zealand, so it's going to take a few years to use those together*" (P-03). Even though New Zealand construction industry is reluctant to adopt new technologies (NZPC, 2012), it was noted that 2 out of 12 participants (P-06 & P-10) endorsed using Building Information Modelling (BIM) for their productions.

Delivery of prefabricated elements is one of the significant stages in the prefabricated housing construction. Since most of the components are manufactured in a factory, delivery of those into the site should receive significant attention. New Zealand's landscape is hilly and transportation of heavy modules across the country is quite a challenge, and thereby, transportation incurs a significant cost. This is emphasised by one of the participants' statements that "*in New Zealand, the land is very heavy and skinny. Therefore, transportation is difficult, and it takes a significant amount of money to transport heavy modules*" (P-03). However, 3 out of 12 participants disagreed with this view and explained that "*even though New Zealand has a skinny land we can manage transportation as there are trucks to deliver*" (P-01).

Suppliers and clients in the supply chain of prefabricated modular components manufacturing seem to be engaged based on a project basis and are discharged when the project is completed. During the interviews, this was emphasised by one participant that "*we don't have any agreements with the suppliers, we select them based on our past experience and sometimes by quotations*" (P-08). Lack of long-term and stable relationships create conflicts in finding trustworthy and cooperative suppliers and clients and thereof organisations have to waste time and effort in tendering for the selection of suppliers. This hinders the opportunity for gaining trust among the stakeholders in the long run. Therefore, trust among the stakeholder has become one of the major concerns in building long-term stable relationships to integrate the business functions.

Suggestions to improve the supply chain of modular components

The interviewees were asked to suggest solutions for the barriers and barriers in both modular bathroom pods and wall panel manufacturing processes. The following are the suggestions identified through the interviews.

Inadequate information sharing in the inception and design development stage would be a challenge to capture the clients' requirement to design the prefabricated element. To avoid this, as participants mentioned open information sharing should be encouraged. In the meantime, the manufacturer/ respondent party of the manufacture needs to actively participate in exchanging design criteria based on the production capacity. As noted, in prefab housing construction designers encourage the early involvement of builders in the designing process to avoid changes after the design freeze and to improve buildability and avoid changes. This is identical to the literature sources, where (Kamali & Hewage, 2016; Pan *et al*., 2012)), highlighted the importance of encouraging clients to participate actively in the designing process to avoid unnecessary assumptions.

Throughout the whole process, communication should be standardised, reliable and accurate to improve the coordination and efficiency. Interviewers highlight the importance of having "*a standard platform for communication"* (P-10) to improve the coordination of the manufacturing process. Having an integrated network to share information through the whole supply chain including suppliers and clients will be beneficial in sharing reliable and accurate information (Lessing, 2015). Organisations need to invest in modern technologies and software applications to allow a better flow of information. Modern information technology provides better sources to share information along the supply chain and avoid delays and disruptions in the process. Having access to open, reliable and accurate information is benefited for all the stakeholders in their decision making. However, "*technical barriers in the New Zealand construction industry*" (P-01) (PrefabNZ, 2014) is a challenge in integrating the manufacturing process in the New Zealand construction industry.

Early design freeze and less flexibility for changes in prefabrication create the requirement of a proper plan with schedules to eliminate complications (Jaillon & Poon, 2008). Production planning with adequate documentation is required to avoid delays and disruptions in the production process. According to the interview findings, participants highlighted the importance of having "*a system/software to production planning and delivering to the relevant parties*"(P-08; P-12). In the meantime, one of the participants endorsed the requirement of providing training to the production team on software handling and supply chain management.

In the production stage, the practice of real-time measuring is hard to find in New Zealand. It is a significant drawback in achieving deadlines and improving productivity. Since the main idea of transferring construction activities from on-site to a factory is to avoid delays from disruptions, operations in the production process should be efficient. Real-time measuring will guide top-level managers/ decision-makers to monitor the current productivity level and based on its analysis; production can be improved further. A systematic performance measurement system and a real-time analysis are required to analyse and continuously improve the production process. Real-time performance measures facilitate evaluations of the performance and thereby, it can be used for decision making and future expansions. This is reflected in the following comment made by a participant. "*Real-time performance monitoring will facilitate improvements to the continuous production line*" (P-05).

Lack of long and stable relationships with clients and suppliers is a challenge in forecasting demands and procurement process respectively. In the New Zealand construction industry, relationships with suppliers and clients are mostly short term and are at arm's length. To rectify this, agreements and contracts were found to be a solution in the early '90s (Saad, Jones & James, 2002). However, this was superseded with the emergence of "partnering" as agreements and contracts appeared with more complications (Saad *et al*., 2002).

Lack of trust among participants is another challenging problem across the whole manufacturing process. Specifically, unskilled labourers in the manufacturing are hired based on short-term contracts and this will create less allegiance towards their work. This could be achieved through long-term relationships and it can significantly affect improving coordination and integration in the process (Kosela, 1999; Spekman *et al*., 1998). This is similar to the interview findings, in which they (11 out of 12 participants) highlighted the requirement of managing long-term relationships and 2 out of 12 participants (P-03 & P-09) disclose that they have partnerships with clients and suppliers.

Logistic management is another important aspect to consider in supply chain management. Logistic management could eliminate the problems associated with the transportation of modules. Here, proper coordination in the transportation of prefabricated elements is required to avoid idling time and storage problems. According to the participants, "*a transportation plan could help to coordinate the delivery process across New Zealand* " (P-10).

A framework of barriers and enablers in prefabrication modular element supply chain

The above barriers and enablers identified from interviews were mapped into the supply chain of modular prefabricated units in New Zealand as shown in Figure 5. This framework is applicable only for modular bathroom pods and wall panel manufacturing as it was developed based on the stages of theses manufacturing processes from the initial idea discussion with the client to the final installation on-site. The stages of this framework include the idea, design, planning, procurement, manufacturing, transportation and on-site assembly. The framework will be useful for the prefab wall panel and bathroom pods manufacturing companies to identify the barriers and enablers for SCI under the aforementioned stages. For the purpose of identification, barriers; managerial, technical and relationship barriers and enablers were labelled as 'M', 'T', 'R' and 'E' respectively (Figure 3).

Idea phase

The most common barriers identified in this stage are inadequate information on the demand (M.05) and lack of stable and tong-term relationships (R.01) with clients. Inadequate information sharing on the clients' requirement (T.01) is another challenge in the inception stage as it hinders the early project execution. Respondents suggested developing demand forecasts based on market surveys (E.IV) to forecast future demands (Projects). Partnering and alliancing (E.VII) was suggested by the respondents to avoid the barriers in the initial stage of manufacturing. This is similar to literature findings where Lessing (2015) suggested manufacturers improving collaborative relationships with clients to receive constant demand for projects as it facilitates the team to start projects early. Open information sharing (E.V) using an integrated system (E.VI) to share basic ideas across the supply chain is suggested to avoid the loopholes in information sharing.

Design phase

In the design phase, lack of clear direction and guidance from the clients (M.04), open information sharing (T.01) and lack of technology used to design (T.02) are common barriers. According to Dainty, Moore and Murray (2007), information transfer and communication is the most frequent challenge in the design phase within the design team and between the design team and client. Unlike the traditional construction, in prefabrication design is unable to change after the design stage. Therefore, respondents suggested improving information sharing through an integrated system using information and communication technology (ICT) (E.V & E.VII). Tjell and Bosch-Sijtsema (2015) suggested the collaborative engagement of clients and design team to improve the mutual understanding and interest in sharing and receiving knowledge and information regarding the clients' needs and wishes.

Planning phase

Under the planning phase, poor project planning (M.01) and lack of goal-setting (M.02) can be identified as common issues. Lack of participation of suppliers and manufacturers in the planning stage (T.01) is another barrier in accomplishing targets of the project. This coupled with a lack of technology used to prepare schedules (T.02), creates chaos in the production process. According to the respondents, implementation of proper project planning and scheduling systems (E.II & E.VI) and establishing common goals could eliminate poor project planning, lack of technology and lack of goal-setting respectively. In line with this, Lessing (2006) recommended having a systematic plan with daily basis schedules to manage the manufacturing process from start to end to achieve productivity.

Procurement phase

The efficiency of the procurement stage is mainly affected by casual relationships with suppliers (R.01) and lack of demand forecasting (M.05). Respondents suggested using a real-time monitoring system (E.IV) integrated with a project planning system (E.VI) to forecast the material demand ahead of time. To avoid delays and complications due to casual relationships with suppliers, respondents suggest maintaining partnerships with regular suppliers (E.VII). Pan et al. (2008) suggested retaining long and stable relationships with suppliers to manage the risks in procurement by reducing dependence on supply. Lack of information sharing (T.01) is another barrier in this phase as its the main success factor of procurement stage (Pan, Gibb, & Dainty, 2008). In practice, there is less overall attention is given to this stage than it appears and it causes delays to the whole process.

Manufacturing phase

Lack of production planning (M.01), automation (T.02) and open information sharing (T.02) can be identified as the main barriers in the production stage. Moreover, the lack of clear directions and guidance towards the machine operators (M.04) will create defects and errors in the production (Lessing *et al.*, 2015). Even though prefabrication is about improving efficiency, performance monitoring and improving (M.03) seems to be hardly practised in the production stage. Real-time performance monitoring (E.III) is required to observe and improve the productivity of processes by analysing the records (Lessing *et al.*, 2015). Unstable and short-term basis employment (specifically unskilled workers) (R.01) in the production process, hinders the cooperation and trustworthiness (Koskela, 2000) and thereby creates delays to the whole production process. Having a long and stable relationship (E.III) with participants of the production process saves time and effort in recruiting seasonal employees for the production (Lessing *et al.*, 2015). Respondents suggested training and educating the participants on supply chain management (E.VIII) to avoid the barrier - lack of understanding of the concept of SCM (M.06).

Transportation phase

According to Ying, Tookey and Roberti (2015) logistics apparently incur unnecessary cost and delays due to lack of automation. Further, they emphasised that the major problem in supply chain implementation in the New Zealand construction industry is related to logistics management, which is still not recognised by the industry. This is mainly caused by the lack of automation (T.02) and miscommunication between the parties (M.04 & T.01) in the delivery stage. Transportation of volumetric modules (T.03) is another challenge as the geography of New Zealand is mostly steep hilly. Proper logistics management (E.IX) is recommended by the respondents to overcome the barriers in this stage.

On-site assembly stage

The stage of on-site assembly can be challenging due to overlapping schedules in the project and module production. Miscommunication (T.01) and inadequate planning (M.01) are identified as major barriers in this stage. Respondents suggested improving open information sharing (E.V & E.VI) to avoid delays and disruptions due to miscommunication. Performance monitoring of the production (E.III) and on-site construction should be encouraged in order to prevent idle times. Lack of automation (T.02) can be categorised as another challenge in this stage as it hinders quick installation of the modular units on-site.

Regarding the barriers mapped with stages of the supply chain, it could be inferred that lack of information sharing, inadequate technical system and poor planning are the major issues which reputedly impact supply chain integration in module manufacturing.

CONCLUSION

The low-level uptake of prefabrication in New Zeland housing construction industry has been affected by many reasons. Intricacies in the supply chain of prefabrication manufacturing is one the reasons for this lower uptake. To address this issue, the paper presents the barriers and enablers for SCI through a framework. The framework is an illustration of the barriers and enablers for SCI in the module elements manufacturing and will provide a guide for the wall panel and bathroom pods manufacturing companies to improve integration across the whole manufacturing process. This framework could be benefited for the house building industry to improve the relationships and collaboration with the prefab manufacturers to increase the efficiency in the construction process. Since a single project focus nature hinders the application of SCI in the traditional construction, this framework may not be applicable for the whole supply chain of traditional house building. However, most of the barriers identified in the framework has been explored by earlier research for traditional construction. Therefore, research considering the applicability of this framework to the traditional house building will be useful. As we have pointed out only the internal barriers for SCI for prefab elements manufacturing, research considering the external barriers will help to improve the efficiency of the process further.

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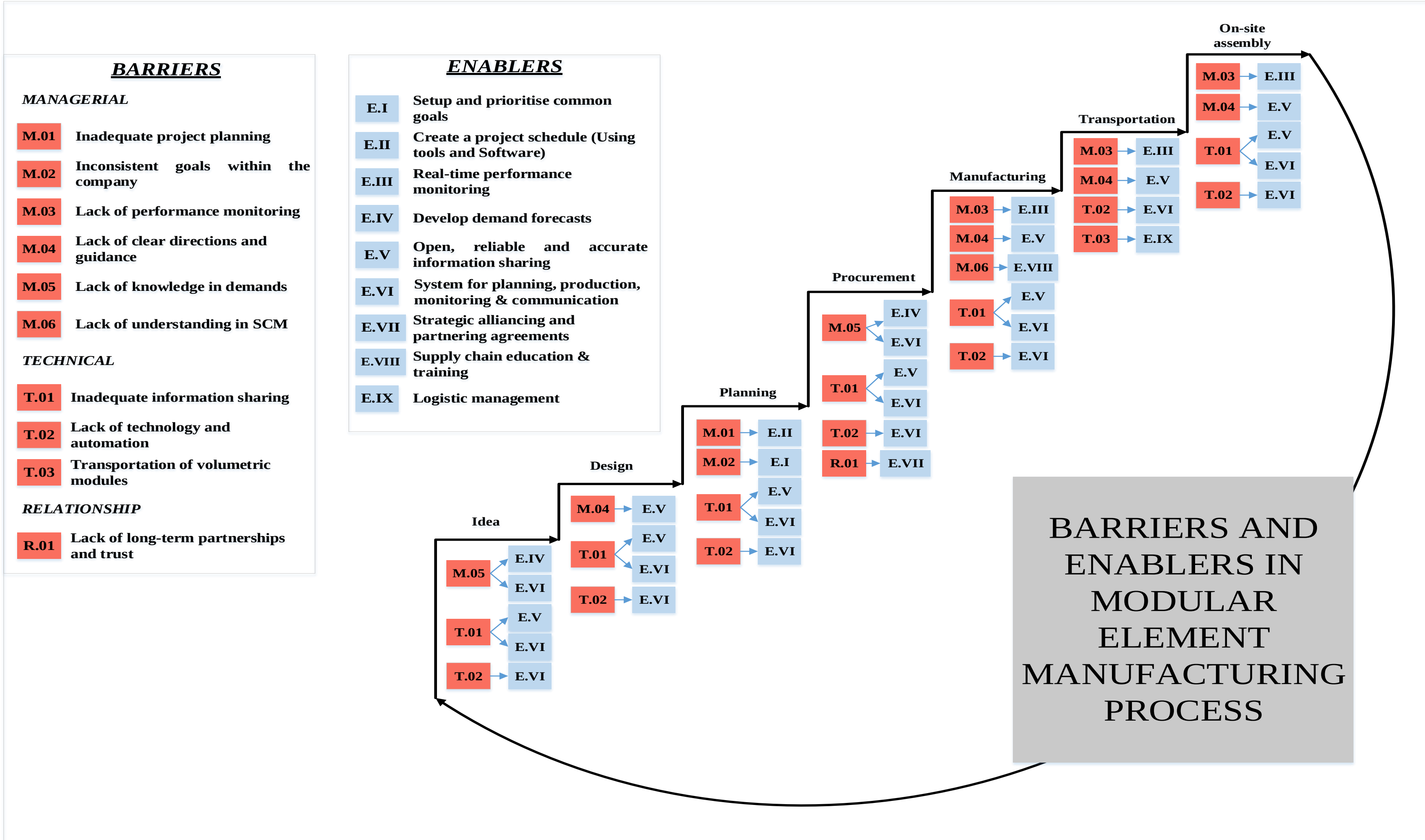

Figure 3: Barriers and enablers in supply chain integration