Ameliorating Supply Chains of Prefabricated Housebuilding: An Integrated Performance Framework

Rehan Masood *[1], Krishanu Roy [2], Vicente A. Gonzalez [3], James B.P. Lim[4]

1- Rehan Masood, Ph.D. (*Corresponding Author)
Affiliation: Doctoral Scholar, Department of Civil and Environmental Engineering, The University of Auckland, Auckland, New Zealand
Mailing Address: City Campus, The University of Auckland, Auckland, New Zealand 1023.
Email address: rmas769@aucklanduni.ac.nz
Phone: +64 20 40775448

2- Krishanu Roy, Ph.D.
Affiliation: Senior Lecturer, School of Engineering, University of Waikato, Hamilton, New Zealand
Mailing Address: University of Waikato, Hamilton 3240, New Zealand.
Email address: kris.roy@waikato.ac.nz
Phone: +64 223917991

3- Vicente A. Gonzalez
Affiliation: Professor and Tier 1 Canada Research Chair in Digital Lean Construction, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, T6G 2R3, Canada and Adjunct Professor, University of Auckland, Auckland, New Zealand
Mailing Address: 12 University of Alberta, Edmonton, Alberta, T6G 2R3, Canada.
Email address: vagonzal@ualberta.ca
Phone: +1 780-492-3111

4- James B.P.Lim, Ph.D.
Affiliation: Professor, School of Engineering, University of Waikato, Hamilton, New Zealand and Adjunct Professor, The University of Auckland, Auckland, New Zealand
Mailing Address: University of Waikato, Hamilton 3240, New Zealand.
Email address: james.lim@waikato.ac.nz
Phone: +64 22 417 5301

ABSTRACT

Prefabrication construction has proven sustainability and affordability through innovative solutions. Prefabricated housebuilding companies, as supply entities, play a vital role towards successful projects using prefabricated products. Many companies go into liquidation due to poor performance. Supply chain management performance is linked with organizational performance in the manufacturing domain. However, there is no performance framework to date for prefabricated housebuilding companies using supply chain management theory. The purpose of this study is to identify the supply chain management interventions in prefabricated housebuilding research and report relevant key performance indicators based on empirical evidence. These indicators were classified under performance dimensions and supply chain processes. These indicators were then checked for relevancy with subject matter by academic and industry experts engaged in prefabricated construction research and practice, respectively. Later an industry-wide Likert scale-based survey was conducted with experienced experts in practice, involved in the prefabricated construction business, for validation of the proposed framework. This study reports forty key performance indicators, ranked under six principal component bodies of supply chain management, with low to high ranges from marketing to strategic management. The purposive selection is used for industry consultation with experts having practical experience. Survey results show all the indicators are highly significant except "supplier-driven strategy" which is still under a medium range of relative importance index. The top six key performance indicators are "Collaborative networking", "Quality assurance", "Entrepreneurial cognition", "geographical proximity", "intellectual property" and "Relationship marketing". The performance framework is suitable for vertically integrated companies involved in design, manufacturing, and construction. A qualitative nature of framework is highly useful, with implementation ease, for the companies to benchmark and gauge performance in a competitive market. This study explored the general supply chain management theoretical intervention for the development of an integrated performance framework as only specific elements were considered previously.

Keywords: Prefabricated housebuilding; Supply chains; Integrated performance framework; Supply chain management; Principal component bodies; Suppliers; Organizational performance; offsite construction; Industrialized housebuilding

INTRODUCTION

Prefabricated construction (PC) has the potential to achieve affordability and sustainability in house building. This enhanced the involvement of the supply chain (SC) with more work happening offsite (Vrijhoef & Koskela, 2000), changing the industry dynamic from projects to products (Bertram et al., 2019). Nevertheless, the role of supply organisations has become critical to the adoption of PC. Prefabricated house building (PHB) (Schoenwitz, Potter, Gosling, & Naim, 2017) companies are supply organisations for prefabricated components, panels, modular and whole buildings, playing SC roles as manufacturer, supplier, subcontractor or builder (Rehan Masood, Lim, González, Roy, & Khan, 2022) in the house building sector. Despite other members in the SC of house building, these companies are more vulnerable, having different levels of interdependency and engagement (Forbes & Ahmed, 2010, p. 128) with a higher risk share of implementing the PC technologies on the projects (R. Masood, Roy, Gozález, Lim, & Nasir, 2023). Most PHB companies went into receivership within a few years of their establishment (Taylor, 2022). PHB companies have been persistent in facing critical performance challenges of the last two decades (Dainty, Millett, & Briscoe, 2001; Rehan Masood, Lim, & Gonzalez, 2021) which need to be addressed to attain survival as well as growth.

Supply chain management intervention for Prefabricated housebuilding (PHB) performance

Improvement in the supply chain management (SCM) practices is directly linked with the organizational performance (Gandhi, Shaikh, & Sheorey, 2017) and integrated project delivery as well (R. Jin, Gao, Cheshmehzangi, & Aboagye-Nimo, 2018). SC, in PHB context, "*comprises the complete package of concept, design, detailing, manufacture and erection*" (Elliott, 2017). However, SC complexity increases with prefab type, from intra-supply chain (organizational) to inter supply chain (project-based) (Hussein, Eltoukhy, Karam, Shaban, & Zayed, 2021). SC maturity is the least under researched topic in offsite construction literature (G. Liu, Nzige, & Li, 2019), while intelligentization and informatization are the most researched within this domain (Han, Yan, & Piroozfar, 2022). However, SCM from an organizational perspective is still incipient (Rehan Masood et al., 2022).

Literature on performance frameworks using supply chain management theories

Researchers attempted to develop frameworks and models to understand and measure the performance of PHB companies; however, limited studies focused on relevant SCM theories. Some notable works are reported here. The foremost attempt at developing a framework for the industrialization of PHB companies was based on integrated lean and SCM theories (J Lessing, 2006). The performance framework by Halman and Voordijk (2012) is based on balanced scorecard theory with sources from manufacturing literature. Yashiro (2014) conceptualized SC maturity based on prefab types. Value-based modelling by Sahin, Miller, and Mohamed (2016), is based on system dynamics to create value from manufacturer and industry perspective. Goh and Loosemore (2017) used a resource-based view to determine the impact of offsite technology at the organisational level. K. Liu, Su, and Zhang (2018) used maturity theory to manage SCs (i.e., prefab suppliers) from a project perspective. Xun, Kang, and Zhao (2019) developed an operational model based on a SC operations reference for PHB companies. Sooriyamudalige, Domingo, Childerhouse, and Shehzad (2020) developed a framework that illustrates barriers and enablers for SC integration. A process-oriented framework based on lean manufacturing principles was developed by Youyi Zhang, Lei, Han, Bouferguene, and Al-Hussein (2020). Stehn, Engström, Uusitalo, and Lavikka (2020) explored dynamic capabilities based on a resource-based view. SC capabilities for PHB companies to achieve SC resilience were reported by Ekanayake, Shen, and Kumaraswamy (2020). Grenzfurtner, Rudberg, Loike, Mayrhofer, and Gronalt (2021) used business strategies that led companies to develop specific features within their performance management system and showed which specific indicators are relevant for managing on-site performance. Sustainability triple tier: social, economic and environmental, were also investigated to develop performance indicators for prefab SCs (YD Zhang, Yang, Pan, & Pan, 2021; Zhao, Wang, Ye, Huang, & Si, 2022). Assessment model for interface management was developed to imporve the logisitc process in SC (S. Zhang, Li, Li, & Yuan, 2022). A dialectical system framework has been developed for enhancement of modualr construciton supply chain with focus on seven components (Pan, Pan, &

Yang, 2023). The trend is adopting mature SCM theories from manufacturing to offsite construciton for developing performance frameworks or models (Rehan Masood et al., 2022). However, none of the research studies considered the principal component bodies (PCB) for general SCM theory to develop a performance framework for PHB companies.

Organization of Paper

This study is an attempt to develop an integrated performance framework (IPF) SCM-driven best practices reported in empirical studies. In phase 1, a literature review was conducted to identify the best practices for designing the key performance indicators (KPIs). KPIs are further classified for performance dimensions (PDs) and organizational supply chain processes (SCP). In phase 2, a questionnaire survey was then conducted with Prefab industry experts to validate the IPF for PHB companies. Lastly, the application of the IPF, the contribution of the research, and its limitations were discussed.

RESEARCH METHOD

This study follows a positivist research approach to using the SCM theory (Schweber, 2015). There are two main phases.

Phase 1: Design of IPF

In this phase, IPF was designed based on the literature review. Most recurring themes were extracted from the systemic literature review on the SCM within PHB research focusing on suppliers perspectives (Rehan Masood et al., 2022). These themes are driven by six PCBs of SCM by Croom, Romano, and Giannakis (2000), including strategic management (STM), relationships (REP), logistics (LOG), best practices (BST), marketing (MKT), and organizational behavior (ORB).

Best practices were then identified towards developing key performance indicators (Castillo, Alarcón, & Pellicer Armiñana, 2018), with an extensive literature review of relevant studies published in the last 10 years, establishing the grounded theory of SCM for PHB (Knight & Ruddock, 2009, p. 88). Search string on Google Scholar (Ayodele, Chang-Richards, & González, 2020) for specific KPI, for example, *"intellectual property" "prefabricated construction" OR "Offsite construction" OR "Modular construction" OR "offsite manufacturing" OR "prefabricated housebuilding" "case study" "house" OR "housebuilding" "supplier" OR "manufacturer" "performance"; custom range: 2013 to 2023; sort by relevance*. Only peer-reviewed construction focused journal articles were selected (Fellows & Liu, 2021, p. 141) with case study research method, for validation of the theoretical elements (Schweber, 2015). Google Scholar is suitable for construction related search, and retrieved articles with higher relevance and citation score (Martín-Martín, Orduna-Malea, Thelwall, & López-Cózar, 2018) that were found in initial 1-2 search pages. It was ensured that the articles focused on PHB company organizational performance having clarity on specific KPI with relevancy for performance dimension and SC process with empirical intervention. All the review studies with only theoretical contributions and surveys or interview studies without empirical intervention, also, conference, books and reports sources were excluded from the selection process.

KPIs were also classified against the performance dimensions (Miltenburg, 2005) and organisational SC processes (Lambert & Enz, 2017). Performance dimensions have interrelations (Rehan Masood, Roy, Gonzalez, Lim, & Nasir, 2023) and include cost (C), quality (Q), features (F), delivery (D), flexibility (L), and innovation (I). SC processes include customer relationship management (CRM), supplier relationship management (SRM), customer service management (CSM), demand management (DM), order fulfillment (OF), manufacturing flow management (MFM), product development and commercialisation (PDC) and return management (RM). The IPF has been designed considering the PHB companies involved not only in production (manufacturing, pre-assembly and subassembly) but also vertically integrated with design and sales in upstream and transportation and on-site installation in down-stream (Gann, 1996).

The proposed performance measurement scale for IPF is standardized and applicable to all KPIs. The scale is qualitative, comprised of five-points demonstrating the implementation of the best practices (Kourtzanidis, Angelakoglou, Apostolopoulos, Giourka, & Nikolopoulos, 2021). The scale is described as, 0 – No awareness; 1 – Awareness but no implementation; 2 – Not fully implementation; 3 – Full implementation; 4 – Enhanced implementation.

Phase 2: Evaluation of IPF

Initially, the content and thematic validation were achieved through consultation with two experts. One was a NZ University PhD faculty member with more than 10 years of research experience in offsite manufacturing. The other was OffsiteNZ's former CEO, who had more than 20 years of prefab experience. This is essential to determining the relevance of the subject matter (Beck & Gable, 2001). The designed IPF has been validated through industry expert opinions collected through an online questionnaire survey to save time and avoid face-to-face meeting constraints (Z. Jin, Deng, Li, & Skitmore, 2013). Ethical approval (023539) was obtained from the human participants' ethics committee to conduct the survey.

Purposive sampling was adopted to select the industry experts (Knight & Ruddock, 2009), who had relevant prefab experience in the New Zealand context. All the PHB companies categorized under the "manufacturer" category of the OffsiteNZ (https://www.offsitenz.com/directory) were approached, and only twelve valid responses were finalized (41.37%), a good representative of the prefab industry by sample size i.e. 14 (Halman & Voordijk, 2012), country context (Sooriyamudalige et al., 2020) i.e. 12 and based don experience only six (Palacios, Gonzalez, & Alarcón, 2014). These are product-oriented (Jerker Lessing & Brege, 2018) and vertically integrated (Rehan Masood et al., 2022) companies, having technology-based manufacturing and/or assembly as core business (Das, Hijazi, Maxwell, & Moehler, 2023).

< Table 01 >

Table 1 shows the profiles of the selected industry experts and representative of prefab industry in New Zealand. All the participants were positioned in managerial roles in PHB companies, involved in either managing the whole SC or part, posing relevant areas of expertise; 83% have more than 5 years of experience in the PHB industry and engage in a variety of prefab types ranges (R Masood & Roy, 2022); component (C), non-volumetric (NVA), volumetric (VA), modular (M) and hybrid (H).

The questionnaire design focused on demographics, SC understanding, and common performance measures, and proposed KPI agreement levels through 5-point Likert scale (Boone Jr & Boone, 2012).

Participants were asked for their understanding of SCM definition by Cutting-Decelle et al. (2007) as: "*Managing supply chain efficiently and effectively has the potential to improve the performance of Prefab supplier firms to deliver the right product at the right time with right quality, cost and service*." Further, they were asked for common performance measures used in the prefab industry (Gunasekaran, Patel, & Tirtiroglu, 2001) such as lead time (order to delivery), product cost, product quality, serviceability, flexibility, inventory stock, inventory cost, large product portfolio, customer satisfaction etc.

KPIs significance agreement level was evaluated through 5-point Likert scale (Boone Jr & Boone, 2012), where "1" indicates not at all significant to "5" as extremely significant. Cronbach's α was applied to determine the internal reliability of the IPF based on multiple KPIs (Cronbach, 1951, p. 304), following Eq. and 2.

$$\alpha = \left(\frac{k}{k-1}\right)\left(1 - \frac{\sum_{i=1}^{k} \sigma_i^2}{\sigma_t^2}\right) \quad (1)$$

$$\sigma_t^2 = \sum_{i=1}^{k} \sigma_i^2 + \sum_{i=1}^{k} \sum_{j=1}^{k} \sigma_{ij}^2\,, \ (i \neq j) \quad (2)$$

Where k = number of KPIs in scale, σ_i^2= variance of KPI *i*; σ_t^2= total variance of scale; σ_{ij}^2= covariance of items *i* and *j*. α value greater than or equal to 0.60 is considered reliable (Nunnally & Bernstein, 1994).

The relative importance of each KPI was determined by relative importance index (RII) values, using the following equation (Wu et al., 2019), following Eq. 3:

$$\text{RII} = \Sigma \text{W}/(\text{A} * \text{N}) \quad (3)$$

where: W – weight of each factor (i.e., 1–5); A – highest weight (i.e., 5); N – total number of respondents.

The importance scale for RII by Akadiri and Olomolaiye (2012) was used: high (H) (0.6≤ RII≤1.0), medium (M) (0.4≤ RII≤0.6), and low (L) (0.0≤ RII≤4.0).

INTEGRATED PERFORMANCE FRAMEWORK

This framework is comprised of forty KPIs based on best practices, categorized by six PCBs. These KPIs were further classified by performance dimensions and SCM processes.

< Table 02 >

STM - Strategic Management

The organisational performance of PHB companies is highly dependent on the strategic management, which has inexorable links with SCM (Ketchen & Giunipero, 2004). STM_1 places on the intellectual property, which gives a competitive edge to PHB companies both locally and internationally. STM_2 is about how well the PHB companies comply with the building code, such as by obtaining CodeMark to certify the products. STM_3 indicates the social responsiveness of the PHB companies to societal issues such as affordability and sustainability. STM_4 demonstrates the integral position of the PHB company in the organization of the prefab projects. STM_5 is linked to the operational capability for dealing with customers for products with low to high customization. STM_6 referred to the systematic approach of PHB companies to regularise the orders through continuous improvement in onsite integration, SC control, and governance and learning from co-experience with other stakeholders. STM_7 focused on the readiness of PHB companies to get involved in the projects using OSM, preferably in the initial phase. STM_8 emphasises the power of the PHB companies to shape the strategy to value the projects, with standardised components having flexibility in use and maintenance.

REP – Relationships

PHB companies must develop relationships for SCM integration primarily based on trust and commitment (Tan, 2001). REP_1 indicates the long-term collaborative relationships with customers based on information and knowledge sharing. REP_2 demonstrates the horizontal collaboration with complementing and competing companies through sharing at multiple levels. REP_3 places on the establishment of the collaborative network among down-stream SC members, considering the causality and closeness. REP_4 focused on the engagement in a possible strategic partnership to enhance the buyers and to keep the business running. REP_5 refers to the utilisation of outsourcing to gain operational efficiency and profitability. REP_6 highlights the capability to maintain the social linkage with industry through frequent engagement and intense connections.

LOG – Logistics

Logistics defined the material flow and transportation of prefab products (Cooper, Lambert, & Pagh, 1997). LOG_1 indicates the onsite integration through joint planning towards mutual understanding ofr logistic requirements. LOG_2 refers to the inclusion of third-party logistics in delivery. LOG_3 places on postponement strategies for onsite operations to manage the schedule risk. LOG_4 highlights the capability to optimise the schedule of delivery with proper planning. LOG_5 demonstrates the inclusion of RFID for real-time monitoring. LOG_6 focused on the manufacturing and/or assembly facility that was near the source market and accessible to the customers.

BST – Best practices

The best practices intervention aims for SCM improvement (Lamming, 1996). Best practices are driven by relevant theories and frameworks with empirical characteristics. BST_1 indicated the process synchronisation of manufacturing for just-in-time delivery. BST_2 refers to BIM applications for the digitalization of SCM phases. BST_3 places on the information integration through block chain and the internet of things. BST_4 is mapping the value streams for each product family to identify and eliminate waste. BST_5 is the adoption of a business model following the economic circularity principles. BST_6 is the implementation of enterprise resource planning to manage the resources proficiently. BTS_7 focused on smart contracting for contractual and financial transparency. BST_8 demonstrates the management of organisational quality through establishing control points. BST_9 is the management of the product design for adaptation driven by scenarios based on coordination.

MKT – Marketing

Marketing helps in capturing the customers through the right advertising (Min & Mentzer, 2000). MKT_1 demonstrates the strategy for market integration with value-added offering. MKT_2 refers to the application of an ambidexterity strategy for competitive pricing. MKT_3 places on using the catalogues in running the advertising campaigns. MKT_4 establishes the long-term relational coordination for traction based on intense interaction. MKT_5 focuses on the effective customer evaluation for inventory management through product portfolios.

ORB – Organizational behavior

Organisational behaviour is the learning of the PHB company to gain from internal and external pressures (Holt & Ghobadian, 2009). ORB_1 indicates the capacity to reposition to enhance the control. ORB2 utilises of information technology compatible with prefab technology. ORB_3 places emphasis on the knowledge sharing for improvement in products and processes driven by experiences. ORB_4 demonstrates human resource development by providing opportunities for training and a safe workplace. ORB_5 refers to the engagement of customers based on quick feedback. ORB_6 highlights the adoption of entrepreneurial cognition for innovation.

Performance dimensions of KPIs

The performance dimensions of the KPIs are associated based on the interrelated domains of process, technology, people, and product (Nadim & Goulding, 2011), considering the PHB SC as design, manufacturing, and construction (Goulding, Pour-Rahimian, Arif, & Sharp, 2015). The *Cost* performance dimension indicates the management of incurred expenses and overheads. The KPIs which improve the cost performance are STM_1, REP_5, BST_4, BST_7, MKT_1, MKT_5, and ORB_4. The *Quality* performance dimension is about the management of the conformance measures as per specifications. These KPIs are classified under this dimension, STM_2, LOG_5, BST_2, BST_3, BST_8, and ORB_3. *Features* performance dimension is linked with the management of product competing attributes considering design, manufacturing (and or assembly), and onsite operations. STM_3, STM_6, STM_7, REP_2, LOG_1, BST_6, BST_9, MKT_4, ORB_2 and ORB_5 are linked to this dimension. The *Delivery* performance dimension demonstrated the shortened lead time with logistic adequacy. Relevant KPIs are REP_3, REP_4, LOG_2, LOG_4, LOG_6, and BST_1. The *Flexibility* performance dimension refers to the balancing the standardisation and customization for product and processes. STM_5, STM_8, LOG_3, MKT_2, and ORB_1 are identified under this dimension. The *Innovation* performance emphasis on the adoption of new ways to improve practices. This dimension covers KPIs as STM_4, REP_1, REP_6, BST_5, MKT_3, ORB_6.

KPIs for SCM processes

There are eight SC processes in the organisational context of the PHB company. The *customer relationship management* process helps in developing and maintaining the customers' relationships (upstream). KPIs for this process are REP_1, REP_2, REP_4, and MKT_4. The *Supplier relationship management* process supports the development and maintenance of the suppliers' relations (downstream). KPIs for this process are REP_3, REP_6, ORB_3. *Customer service management* process ensures compliance through by the administration of agreements for products and services. KPIs for this process are STM_7, LOG_3, LOG_5, BST_1, BST_4, and BST_7. The *Demand management* process focuses on the demand and supply balance and synchronisation through variability reduction and flexibility enhancement. KPIs for this process are STM_2, STM_4, STM_5, LOG_4, BST_6, and BST_9. The *Order fulfilment* process maintains order continuity by addressing the customer requests and providing cross-functional feedback through extended network. KPIs for this process are STM_6, MKT_3, MKT_5, and ORB_5. The *Manufacturing flow management* process obtains, implements, and manages flexibility in production through decoupling and configuration. KPIs for this process are STM_8, REP_5, LOG_6, BST_2, BST_3, BST_8, ORB_2, and ORB_4. *Product development and commercialisation* process places on the developing and bringing market-focused products to market. KPIs for this process are STM_1, STM_3, MKT_1, MKT_2, and ORB_6. The *Returns management* process is linked with developing reverse product flow efficiently for avoiding returns and reusability. KPIs under this process are LOG_1, LOG_2, BST_5, and ORB_1.

EVALUATION OF INTEGRATED PERFORMANCE FRAMEWORK

This section reports the key findings of the study.

Understanding of SCM

Participants were asked about their perceptions of the definition of the SCM in the context of PHB companies. All the participants agreed on the mentioned definition, which indicates a general understanding of SCM practices. Further, participants were asked about the common KPIs used in practice. The most common KPIs reported by participants, in ascending order, were lead time, product cost, and quality. Two participants mentioned “DIFOT”, which is defined as “delivered in full on time”. This concept demonstrates the high modularity of the products.

< Table 03 >

Ranking of KPIs by PCBs

The Cronbach’s α value was 0.88 > 0.6, demonstrating the internal reliability of the IPF. In *STM*, STM_1 “Early involvement” has been ranked first. However, STM_5 “Supply capacity”, STM1 “Intellectual property” and STM_4 “Virtual organization structure” are ranked 2, 3, and 4 respectively, having RII above 0.8. STM_3 “social responsive” ranked 5 and STM_6 “order fulfilment” ranked 6 with above 0.7 RII. Only STM_2 “code compliance” above 0.6 RII is ranked 7. The lowest rank “8” is STM_8 “Supplier driven strategy”. In *REP*, REP_3 “Collaborative network” and REP_1 “Collaborative relations” are ranked at first and second position, with relatively high RII scores. Interestingly, REP_2 “Horizontal collaboration” ranked at 3 followed by REP $_4$ “Strategic partnership”, having same RII but slightly vary SD. Remaining REP_6 “industry linkage” is at 5 but REP_5 “Outsourcing” is at 6. In *LOG*, LOG_4 “schedule optimization” and LOG_6 “Geographical proximity”, both ranked first with same RII score and SD, followed by LOG_1 “Re-organizing onsite logistics”. The bottom two ranks are LOG_2 “Third-party logistics” and LOG_3 “Postponement strategy”. In *BST*, BST_8 “quality assurance” is ranked one. BST_4 “Value streaming”, BST_5 “Circular business” and BST_7 “Smart contracting” are ranked at 2, 3 and 4 with similar RII scores but vary SD. BST_3 “design digitalization” and BST_6 “Automated planning” are ranked at 5 and 6, with same RII scores but vary SD. BST_2 “information integration” and BST_9 “Design adaptation” are ranked at 7 and 8 with same RII score but vary SD. The lowest ranked KPI is BST_1 “process synchronization”. In *MKT*, the top rank is MKT_4 “Relationship marketing”, followed by MKT_1 “customer focus” and MKT_5 “Sales management” at 2 and 3. The bottom two KPIs in this PCB are MKT_2 “Competitor initiative” and MKT_3 “Advertising”. In ORB, ORB6 “Entrepreneurial cognition” is ranked first. However, ORB_2 “Technology integration” and ORB_5 “Client engagement” are ranked at second position in this PCB, having same RII and SD values. ORB_4 “HR Development” is ranked 3 and ORB_1 “Organizational structure” is ranked 4, having similar RII score but vary SD. The lowest ranked KPI in this PCB is ORB_3 “Organizational learning”.

Overall Ranking of KPIs

All KPIs score above 0.6 RII except STM8 ("Supplier driven strategy"). However, overall, all the identified KPIs are validated through industry consultation and agreed upon as critical to the performance of PHB companies. 40 KPIs are ranked in 30 positions considering RII and SD scores. There is no single PCB having KPIs with high scores. However, in several instances, KPIs are ranked at same level. STM_7 and REP_3 are ranked first. BST_8 is ranked second, followed by STM_5 and ORB_6 in third. Both LOG_4 and LOG_6 are ranked fourth. STM_1, MKT_4, and BST_4 are ranked fifth, sixth, and seventh. However, both REP_1 and BST_5 are ranked eighth. STM_4 is ranked ninth but both LOG_1 and BST_7 are ranked tenth. Similarly, ORB_2 and ORB_5 got dual position at eleventh. MKT_1 and MKT_5 are ranked at twelve and thirteen, respectively. BST_3 and ORB_4 are at the same rank of fourteenth. The fifteenth rank goes to STM_3. There are three KPIs at rank sixteen, REP_2, BST_6, and ORB_1. REP_4 and MKT_2 are positioned seventeenth. However, REP_6 and BST_2 are at eighteenth and nineteenth, respectively. Later, the KPIs have individual positioning as ORB_3 (20), BST_9 (21), MKT_2 (22), LOG_2 (23), STM_6 (24), BST_1(25), LOG_3 (26), REP_5(27), LOG_5 (28), STM_2(29) and STM_8 (30).

DISCUSSION

In this study, a performance framework has been designed based on theoretical intervention and evaluated through industry consultation. Research in the PHB discipline on SCM focuses on project context SCM. However, with the adoption of the OSM strategy the role of prefab supply entities (Hsieh, 1997), referred to as PHB companies, is enhanced and becomes critical eventually. These companies have the potential to apply business process re-engineering (Childerhouse, Lewis, Naim, & Towill, 2003) to improve the total SC with more control (Iwashita, 2001). The performance framework, having applied nature (easy to implement), helps in keeping the PHB companies competitive enough to survive in the dynamic markets. Previous performance frameworks have not used the core SCM theory, but specific integrated SCM theories or elements were investigated.

SCM originated from manufacturing industry and application in OSM needs research for adaptation of practices, due to inherent incompatibilities (Luo, Zhang, & Sher, 2021). Hence, the SCM practices in manufacturing research need to be investigated for compatibility for OSM. Similar to developing a performance framework based on empirical studies.

PCBs of SCM are pillars of the theory. However, the body of knowledge is expanding through empirical research in SCM and PCBs need to be reviewed for each discipline (Soni & Kodali, 2011). The current framework used PCBs to establish the context of SCM intervention for PHB from an organizational perspective. The number of KPIs identified based on the recurring themes of SCM in PHB research, coverage in ascending order, are BST, STM, REP, LOG, ORB and MKT. More coverage goes to BST due to intervention of Construction 4.0 technologies in managing SC of PHB company to attain industrialisation in true means. However, the role of STM is less important as the PHB company needs to establish a strategic business orientation in the niche market. The role of REP and LOG are equally significant. The least addressed PCB was MKT, as this has not been covered extensively in PHB research. The study significance lies in untapping the general SCM theory from organizational perspective for PHB companies, who played significant role in project supply chain using prefab products.

The KPIs in the performance framework are measured on a qualitative scale of implementation. This has been proposed considering the extensive need for data and information for quantitative measures (Halman & Voordijk, 2012). Furthermore, there are forty KPIs in the current framework with coverage of SCM theoretical elements extensively. However, few performance studies has lower coverage as 12 constructs (J Lessing, 2006) eight subcategories (Yashiro, 2014), six resource based aspects (Goh & Loosemore, 2017) and seven components (Pan et al., 2023). This framework demonstrates relevance of KPIs by performance dimensions which has not been addressed in previous studies. This study reports the effectiveness of KPI in improving one of the core performance dimensions but these dimensions are interrelated. Further, single SC process is not portraying the overall performance of PHB companies (S. Zhang et al., 2022) but this framework demonstrated the linkage with all SCM processes. The industry consultation to validate the framework is a crucial stage, and the participation of relevant practitioners is essential. There is ambiguity in SC elements and SC processes in determining the performance of PHB companies (Pan et al., 2023), that has been addressed in this study by integrating the SC processes and performance dimensions (Rehan Masood et al., 2023). The ranking of the KPIs for each PCB and overall framework determines their significance at the micro and macro levels.

The theoretical contribution of this study is using general SCM theory, based on well-established PCBs, to develop the performance framework for PHB companies. This study is pioneering in addressing the organizational performance of PHB companies through SCM lens. The practical contribution of this study is to provide a performance framework, based on qualitative measures, to PHB companies that opt manufacturing/assembly as business strategy, to remain competitive in dynamic market. It is essential to identify the right KPIs with proper theoretical foundation to avoid overcomplications in performance assessment and maximize the prefabrication benefits from SCs to projects (Masters, Drover, & Patel, 2023, September). However, the same KPIs could be used to determine the performance in comparison to competitors. The framework addresses the OffsiteNZ vision (OffsiteNZ, 2023) to facilitate the current and prospective companies joining and surviving in the prefab sector. On the other hand, an increase of 10%-20% OSM focused on public projects (CCNZ, 2022) will potentially change the market dynamics and performance of PHB companies, will be critical for the success of the projects using prefab products.

CONCLUSION

Improving the SC within PHB organizational boundaries helps in integration well with project SC (Dainty et al., 2001). This study introduces SCM intervention in the organizational performance of PHB companies. This study used frequent elements of SCM under six PCBs within PHB research. The best practices were then derived from these elements as reported in empirical studies. Forty KPIs were designed based on the best practices and classified by six PDs and eight SCPs. The KPIs were scaled for measurement based on the level of implementation. The framework was validated for thematic relevance with experts. An industry survey was conducted to validate the application of the proposed framework. The internal consistency was found significant and only one KPI scored relatively low RII but still within acceptance range.

LIMITATIONS AND FUTURE RESEARCH

This study has limitations that need to be reported. PCBs used for the framework were developed based on the systematic review of SCM within PHB research from an organizational perspective, as general SCM is not applicable to OSM. Further, empirical studies were considered to develop the KPIs based on best practices as survey or conceptual studies still need to be validated. The key assumption is consideration of overlapping and related concepts of SCM with organizational performance theories. Researchers used similar concept without acknowledging the relevance to SCM theory (Tennant & Fernie, 2014). Authors ensure the selected SCM PCBs and KPIs are relevant to SCM within PHB research and proven empirically. Another assumption for framework development is the PHB company's involvement in all key stages of SC, including design, manufacturing, and construction. However, PHB companies are not truly vertically integrated. So, the KPIs should be selected based on their involvement in SC processes. The participants for the validation survey represent the offsite construction community in New Zealand, having affiliation with OffsiteNZ. However, there is a possibility of non-participatory prefab practitioners as non-members to industry association.

In operation research, improving organizational SCM helps in improving the organizational performance (Gandhi et al., 2017). It was hypothesized that it is true for PHB industry which is amalgamation of manufacturing and construction industries. This study has proven that identified SCM elements and relevant KPIs are potentially applicable to measure the performance and industrialization (Costa, Carvalho, Pimentel, & Duarte, 2023) of the PHB companies. The developed framework will be tested for PHB companies in any type of prefab and integrated upstream and/or downstream, shaping several business models. This is the succeeding objective of this study: to report the effectiveness of the framework using case study research method. In case study context, PHB companies need to be involved in different prefab technologies by product and material. There is potential to investigate the interrelationship of the KPIs and PCBs to develop the performance models for PHB companies using SEM. This study set the foundation for further exploration of different PCBs of SCM to determine their relevancy to offsite construction environment.

DATA AVAILABILITY STATEMENT

All data, models, and code generated or used during the study appear in the submitted article.

REFERNCES

Akadiri, P. O., & Olomolaiye, P. O. (2012). Development of sustainable assessment criteria for building materials selection. *Engineering, Construction and Architectural Management, 19*(6), 666-687.

Assaad, R. H., El-adaway, I. H., Hastak, M., & Needy, K. L. (2022). The Impact of Offsite Construction on the Workforce: Required Skillset and Prioritization of Training Needs. *Journal of Construction Engineering and Management, 148*(7), 04022056. doi:doi:10.1061/(ASCE)CO.1943-7862.0002314

Ayodele, O. A., Chang-Richards, A., & González, V. (2020). Factors affecting workforce turnover in the construction sector: A systematic review. *Journal of Construction Engineering and Management, 146*(2), 03119010.

Bakhshi, S., Chenaghlou, M. R., Rahimian, F. P., Edwards, D. J., & Dawood, N. (2022). Integrated BIM and DfMA parametric and algorithmic design based collaboration for supporting client engagement within offsite construction. *Automation in Construction, 133*, 104015.

Beck, C. T., & Gable, R. K. (2001). Ensuring content validity: An illustration of the process. *Journal of Nursing Measurement, 9*(2), 201-215.

Bertram, N., Fuchs, S., Mischke, J., Palter, R., Strube, G., & Woetzel, J. (2019). Modular construction: From projects to products. *McKinsey & Company: Capital Projects & Infrastructure*, 1-34.

Björnfot, A., & Torjussen, L. (2012). Extent and Effect of Horizontal Supply Chain Collaboration among Construction SME. *Journal of Engineering, Project, and Production Management, 2*(1), 47.

Boone Jr, H. N., & Boone, D. A. (2012). Analyzing likert data. *The Journal of extension, 50*(2), 48.

Cariaga, I., & El-Diraby, T. (2012). Assessing the Market Potential for Housing Construction Products in Mexico. *Journal of Construction Engineering and Management, 139*(6), 717-725. doi:10.1061/(ASCE)CO.1943-7862.0000637

Castillo, T., Alarcón, L. F., & Pellicer Armiñana, E. (2018). Finding differences among construction companies management practices and their relation to project performance. *Journal of Management in Engineering, 34*(3), 1-13.

CCNZ. (2022). *Residential building supplies market study*. Retrieved from https://comcom.govt.nz/__data/assets/pdf_file/0013/300703/Residential-building-supplies-market-study-Executive-summary-6-December-2022.pdf

Childerhouse, P., Lewis, J., Naim, M., & Towill, D. R. (2003). Re-engineering a construction supply chain: a material flow control approach. *Supply Chain Management: An International Journal*.

Cooper, M. C., Lambert, D. M., & Pagh, J. D. (1997). Supply Chain Management: More Than a New Name for Logistics. *The International Journal of Logistics Management, 8*(1), 1-14. doi:10.1108/09574099710805556

Costa, F., Denis Granja, A., Fregola, A., Picchi, F., & Portioli Staudacher, A. (2019). Understanding relative importance of barriers to improving the customer–supplier relationship within construction supply chains using DEMATEL technique. *Journal of Management in Engineering, 35*(3), 04019002.

Costa, S., Carvalho, M. S., Pimentel, C., & Duarte, C. (2023). A Systematic Literature Review and Conceptual Framework of Construction Industrialization. *Journal of Construction Engineering and Management, 149*(2), 03122013. doi:doi:10.1061/(ASCE)CO.1943-7862.0002410

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *psychometrika, 16*(3), 297-334.

Croom, S., Romano, P., & Giannakis, M. (2000). Supply chain management: an analytical framework for critical literature review. *European Journal of Purchasing & Supply Management, 6*(1), 67-83. doi:http://dx.doi.org/10.1016/S0969-7012(99)00030-1

Cutting-Decelle, A.-F., Young, B. I., Das, B. P., Case, K., Rahimifard, S., Anumba, C. J., & Bouchlaghem, D. M. (2007). A review of approaches to supply chain communications: from manufacturing to construction. *ITcon, 12*(2007), 73-102.

Dainty, A. R. J., Millett, S. J., & Briscoe, G. H. (2001). New perspectives on construction supply chain integration. *Supply Chain Management: An International Journal, 6*(4), 163-173. doi:doi:10.1108/13598540110402700

Das, P., Hijazi, A. A., Maxwell, D. W., & Moehler, R. C. (2023). Can Business Models Facilitate Strategic Transformation in Construction Firms? A Systematic Review and Research Agenda. *Sustainability, 15*(17), 13022.

Das, P., Perera, S., Senaratne, S., & Osei-Kyei, R. (2021). Developing a construction business model transformation canvas. *Engineering, Construction and Architectural Management, 28*(5), 1423-1439. doi:10.1108/ECAM-09-2020-0712

dos Santos Hentschke, C., Torres Formoso, C., & Echeveste, M. E. (2020). A Customer Integration Framework for the Development of Mass Customised Housing Projects. *Sustainability, 12*(21). doi:10.3390/su12218901

Du, J., Jing, H., Castro-Lacouture, D., & Sugumaran, V. (2019). Multi-agent simulation for managing design changes in prefabricated construction projects. *Engineering, Construction and Architectural Management, 27*(1), 270-295.

Ekanayake, E. M. A. C., Shen, G. Q. P., & Kumaraswamy, M. M. (2020). Identifying supply chain capabilities of construction firms in industrialized construction. *Production Planning & Control*, 1-19. doi:10.1080/09537287.2020.1732494

Elliott, K. S. (2017). Industrial Building Systems (IBS) Project Implementation. In *Modernisation, Mechanisation and Industrialisation of Concrete Structures* (pp. 61-124): John Wiley & Sons, Ltd.

Eriksson, P. E., Olander, S., Szentes, H., & Widén, K. (2014). Managing short-term efficiency and long-term development through industrialized construction. *Construction Management and Economics, 32*(1-2), 97-108. doi:10.1080/01446193.2013.814920

Fellows, R. F., & Liu, A. M. M. (2021). *Research Methods for Construction*: Wiley.

Forbes, L. H., & Ahmed, S. M. (2010). *Modern construction: lean project delivery and integrated practices*: CRC press.

Gandhi, A. V., Shaikh, A., & Sheorey, P. A. (2017). Impact of supply chain management practices on firm performance: Empirical evidence from a developing country. *International Journal of Retail & Distribution Management, 45*(4), 366-384. doi:10.1108/IJRDM-06-2015-0076

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

Gharbia, M., Chang-Richards, A., Xu, X., Höök, M., Stehn, L., Jähne, R., . . . Feng, Y. (2023). Building code compliance for off-site construction. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 15*(2), 04522056.

Goh, E., & Loosemore, M. (2017). The impacts of industrialization on construction subcontractors: a resource based view. *Construction Management and Economics, 35*(5), 288-304. doi:10.1080/01446193.2016.1253856

Goulding, J. S., Pour-Rahimian, F., Arif, M., & Sharp, M. (2015). New offsite production and business models in construction: priorities for the future research agenda. *Architectural Engineering and Design Management, 11*(3), 163-184.

Grenzfurtner, W., & Gronalt, M. (2020a). Continuous improvement of the industrialised housebuilding order fulfilment process. *Construction Innovation*, 1471-4175. doi:10.1108/CI-10-2019-0115

Grenzfurtner, W., & Gronalt, M. (2020b). Developing a continuous improvement perspective for subcontractor involvement in the industrialised housebuilding supply chain. *Supply chain management: An international journal*.

Grenzfurtner, W., Rudberg, M., Loike, K., Mayrhofer, R., & Gronalt, M. (2021). Industrialized housebuilding business strategies and the design of performance management systems. *Production Planning & Control*, 1-14.

Gunasekaran, A., Patel, C., & Tirtiroglu, E. (2001). Performance measures and metrics in a supply chain environment. *International Journal of Operations & Production Management, 21*(1/2), 71-87. doi:10.1108/01443570110358468

Halman, J. I. M., & Voordijk, J. T. (2012). Balanced framework for measuring performance of supply chains in house building. *Journal of Construction Engineering and Management, 138*(12), 1444-1450.

Han, Y., Skibniewski, M. J., & Wang, L. (2017). A Market Equilibrium Supply Chain Model for Supporting Self-Manufacturing or Outsourcing Decisions in Prefabricated Construction. *Sustainability, 9*(11), 2096.

Han, Y., Xu, X., Zhao, Y., Wang, X., Chen, Z., & Liu, J. (2022). Impact of consumer preference on the decision-making of prefabricated building developers. *Journal of Civil Engineering and Management, 28*(3), 166–176-166–176.

Han, Y., Yan, X., & Piroozfar, P. (2022). An overall review of research on prefabricated construction supply chain management. *Engineering, Construction and Architectural Management*(ahead-of-print).

Holt, D., & Ghobadian, A. (2009). An empirical study of green supply chain management practices amongst UK manufacturers. *Journal of Manufacturing Technology Management, 20*(7), 933-956. doi:10.1108/17410380910984212

Hsieh, T.-Y. (1997). The economic implications of subcontracting practice on building prefabrication. *Automation in Construction, 6*(3), 163-174. doi:https://doi.org/10.1016/S0926-5805(97)00001-0

Hsu, P.-Y., Aurisicchio, M., & Angeloudis, P. (2019). Risk-averse supply chain for modular construction projects. *Automation in Construction, 106*, 102898.

Hussein, M., Eltoukhy, A. E. E., Karam, A., Shaban, I. A., & Zayed, T. (2021). Modelling in off-site construction supply chain management: A review and future directions for sustainable modular integrated construction. *Journal of Cleaner Production, 310*, 127503. doi:https://doi.org/10.1016/j.jclepro.2021.127503

Innella, F., Arashpour, M., & Bai, Y. (2019). Lean methodologies and techniques for modular construction: Chronological and critical review. *Journal of Construction Engineering and Management, 145*(12), 04019076.

Iwashita, S. (2001). Custom made housing in Japan and the growth of the super subcontractor. *Construction Management and Economics, 19*(3), 295-300. doi:10.1080/01446190010020417

Jin, R., Gao, S., Cheshmehzangi, A., & Aboagye-Nimo, E. (2018). A holistic review of off-site construction literature published between 2008 and 2018. *Journal of Cleaner Production, 202*, 1202-1219. doi:https://doi.org/10.1016/j.jclepro.2018.08.195

Jin, Z., Deng, F., Li, H., & Skitmore, M. (2013). Practical framework for measuring performance of international construction firms. *Journal of Construction Engineering and Management, 139*(9), 1154-1167.

Ketchen, D. J., & Giunipero, L. C. (2004). The intersection of strategic management and supply chain management. *Industrial Marketing Management, 33*(1), 51-56. doi:https://doi.org/10.1016/j.indmarman.2003.08.010

Knight, A., & Ruddock, L. (2009). *Advanced research methods in the built environment*: John Wiley & Sons.

Kourtzanidis, K., Angelakoglou, K., Apostolopoulos, V., Giourka, P., & Nikolopoulos, N. (2021). Assessing impact, performance and sustainability potential of smart city projects: towards a case agnostic evaluation framework. *Sustainability, 13*(13), 7395.

Lambert, D. M., & Enz, M. G. (2017). Issues in Supply Chain Management: Progress and potential. *Industrial Marketing Management, 62*, 1-16. doi:https://doi.org/10.1016/j.indmarman.2016.12.002

Lamming, R. (1996). Squaring lean supply with supply chain management. *International Journal of Operations & Production Management, 16*(2), 183-196.

Le, P. L., Jarroudi, I., Dao, T.-M., & Chaabane, A. (2021). Integrated construction supply chain: an optimal decision-making model with third-party logistics partnership. *Construction Management and Economics, 39*(2), 133-155.

Lei, Z., Sadiq Altaf, M., Cheng, Z., Liu, H., & Tang, S. (2023). Measurement of Information Loss and Transfer Impacts of Technology Systems in Offsite Construction Processes. *Journal of Construction Engineering and Management, 149*(9), 05023011.

Lessing, J. (2006). *Industrialised house-building: Concept and Processes.* (Licentiate). Lund Institute of Technology, Lund University, Lund, Sweden.

Lessing, J., & Brege, S. (2018). Industrialized building companies' business models: Multiple case study of Swedish and North American companies. *Journal of Construction Engineering and Management, 144*(2), 05017019.

Li, C. Z., Shen, G. Q., Xue, F., Luo, L., Xu, X., & Sommer, L. (2017). Schedule risk modeling in prefabrication housing production. *Journal of Cleaner Production, 153*, 692-706. doi:10.1016/j.jclepro.2016.11.028

Li, C. Z., Zhong, R. Y., Xue, F., Xu, G., Chen, K., Huang, G. G., & Shen, G. Q. (2017). Integrating RFID and BIM technologies for mitigating risks and improving schedule performance of prefabricated house construction. *Journal of Cleaner Production, 165*, 1048-1062. doi:10.1016/j.jclepro.2017.07.156

Li, X., Lu, W., Xue, F., Wu, L., Zhao, R., Lou, J., & Xu, J. (2022). Blockchain-enabled IoT-BIM platform for supply chain management in modular construction. *Journal of Construction Engineering and Management, 148*(2), 04021195.

Liu, G., Nzige, J. H., & Li, K. (2019). Trending topics and themes in offsite construction(OSC) research. *Construction Innovation, 19*(3), 343-366. doi:10.1108/CI-03-2018-0013

Liu, K., Su, Y., & Zhang, S. (2018). Evaluating Supplier Management Maturity in Prefabricated Construction Project-Survey Analysis in China. *Sustainability, 10*(9), 3046. Retrieved from http://www.mdpi.com/2071-1050/10/9/3046

London, K., & Pablo, Z. (2017). An actor–network theory approach to developing an expanded conceptualization of collaboration in industrialized building housing construction. *Construction Management and Economics*, 1-25. doi:10.1080/01446193.2017.1339361

Lu, W., Li, X., Xue, F., Zhao, R., Wu, L., & Yeh, A. G. (2021). Exploring smart construction objects as blockchain oracles in construction supply chain management. *Automation in Construction, 129*, 103816.

Luo, J., Zhang, H., & Sher, W. (2021). A mixed method for measuring incompatibilities between manufacturing approaches and off-site construction. *Engineering, Construction and Architectural Management*. doi:https://doi.org/10.1108/ECAM-07-2019-0358

Martín-Martín, A., Orduna-Malea, E., Thelwall, M., & López-Cózar, E. D. (2018). Google Scholar, Web of Science, and Scopus: A systematic comparison of citations in 252 subject categories. *Journal of informetrics, 12*(4), 1160-1177.

Masood, R., Lim, J. B. P., & Gonzalez, V. A. (2021). Performance of the Supply Chains for New Zealand Prefabricated house-building. *Sustainable Cities and Society*, 102537. doi:https://doi.org/10.1016/j.scs.2020.102537

Masood, R., Lim, J. B. P., González, V. A., Roy, K., & Khan, K. I. A. (2022). A Systematic Review on Supply Chain Management in Prefabricated House-Building Research. *Buildings, 12*(1), 40. Retrieved from https://www.mdpi.com/2075-5309/12/1/40

Masood, R., & Roy, K. (2022). Review on Prefabricted Building Technology. *Scope - Work-based Learning 4: Technology*, 24-30. doi:https://doi.org/10.34074/scop.6004002

Masood, R., Roy, K., Gonzalez, V. A., Lim, J. B., & Nasir, A. R. (2023). Modeling relational performance of the supply chains for prefabricated housebuilding in New Zealand. *Smart and Sustainable Built Environment*.

Masood, R., Roy, K., Gozález, V. A., Lim, J. B. P., & Nasir, A. R. (2023). A supply chain perspective of prefabricated housebuilding diffusion in New Zealand. *Engineering, Construction and Architectural Management, ahead-of-print* (ahead-of-print.). doi:https://doi.org/10.1108/ECAM-10-2022-0941

Masters, K., Drover, K., & Patel, J. (2023, September). Measuring the Benefit of Modern Methods of Construction (MMC). *Thought leadership paper*. Retrieved from https://assets.kpmg.com/content/dam/kpmg/uk/pdf/2023/10/measuring-role-of-mmc.pdf

Miltenburg, J. (2005). *Manufacturing strategy: how to formulate and implement a winning plan.*: Productivity Press.

Min, S., & Mentzer, J. T. (2000). The role of marketing in supply chain management. *International Journal of Physical Distribution & Logistics Management, 30*(9), 765-787. doi:10.1108/09600030010351462

Minunno, R., O'Grady, T., Morrison, G., Gruner, R., & Colling, M. (2018). Strategies for Applying the Circular Economy to Prefabricated Buildings. *Buildings, 8*(9), 125. Retrieved from http://www.mdpi.com/2075-5309/8/9/125

Mossman, A. (2019). Just-in-Time Delivery Requires Just-in-Time Production X2–Sychronising Factory and Site for Successful Prefabrication. *Modular and Offsite Construction (MOC) Summit Proceedings*, 124-132.

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

Nunnally, J., & Bernstein, I. (1994). Psychometric Theory 3rd edition (MacGraw-Hill, New York). In.

OffsiteNZ. (2023). OffsiteNZ Vision Statement. Retrieved from https://www.offsitenz.com/_files/ugd/4fe8d5_c14ba2852c0e462a906bfad18a32707f.pdf

Palacios, J. L., Gonzalez, V., & Alarcón, L. F. (2014). Selection of third-party relationships in construction. *Journal of Construction Engineering and Management, 140*(4), B4013005.

Pan, W., Pan, M., & Yang, Y. (2023). *A dialectical system framework for enhancing the modular construction supply chain.* Paper presented at the Proceedings of the Institution of Civil Engineers-Engineering Sustainability.

Peltokorpi, A., Olivieri, H., Granja, A. D., & Seppänen, O. (2017). Categorizing modularization strategies to achieve various objectives of building investments. *Construction Management and Economics*, 1-17. doi:10.1080/01446193.2017.1353119

Sahin, O., Miller, D., & Mohamed, S. (2016). Value-based modelling: an Australian case of off-site manufactured buildings. *International Journal of Construction Management*, 1-19. doi:10.1080/15623599.2016.1247774

Schoenwitz, M., Potter, A., Gosling, J., & Naim, M. (2017). Product, process and customer preference alignment in prefabricated house building. *International Journal of Production Economics, 183, Part A*, 79-90. doi:http://dx.doi.org/10.1016/j.ijpe.2016.10.015

Schweber, L. (2015). Putting theory to work: the use of theory in construction research. *Construction Management and Economics, 33*(10), 840-860.

Shen, K., Li, X., Cao, X., & Zhang, Z. (2022). Prefabricated construction process optimization based on rework risk. *Journal of Construction Engineering and Management, 148*(6), 04022031.

Soni, G., & Kodali, R. (2011). A critical analysis of supply chain management content in empirical research. *Business Process Management Journal, 17*(2), 238-266. doi:10.1108/14637151111122338

Sooriyamudalige, N., Domingo, N., Childerhouse, P., & Shehzad, W. (2020). Barriers and enablers for supply chain integration in prefabricated elements manufacturing in New Zealand. *International Journal of Construction Supply Chain Management, 1*(1), 73-91. doi:10.14424/ijcscm100120-73-91

Stehn, L., Engström, S., Uusitalo, P., & Lavikka, R. (2020). Understanding industrialised house building as a company's dynamic capabilities. *Construction Innovation*.

Sundquist, V., Gadde, L.-E., & Hulthén, K. (2017). Reorganizing construction logistics for improved performance. *Construction Management and Economics*, 1-17. doi:10.1080/01446193.2017.1356931

Tan, K. C. (2001). A framework of supply chain management literature. *European Journal of Purchasing & Supply Management, 7*(1), 39-48. doi:https://doi.org/10.1016/S0969-7012(00)00020-4

Taylor, M. D. (2022). A definition and valuation of the UK offsite construction sector: Ten years on. *International Journal of Construction Management, 22*(15), 2877-2885.

Tennant, S., & Fernie, S. (2014). Theory to practice: A typology of supply chain management in construction. *International Journal of Construction Management, 14*(1), 56-66. doi:10.1080/15623599.2013.875268

Uusitalo, P., & Lavikka, R. (2020). Overcoming path dependency in an industrialised house-building company through entrepreneurial orientation. *Buildings, 10*(3), 45.

Vrijhoef, R., & Koskela, L. (2000). The four roles of supply chain management in construction. *European Journal of Purchasing & Supply Management, 6*(3–4), 169-178. doi:http://dx.doi.org/10.1016/S0969-7012(00)00013-7

Wang, B., Geng, L., Dang, P., & Zhang, L. (2022). Developing a framework for dynamic organizational resilience analysis in prefabricated construction projects: A project life cycle perspective. *Journal of Construction Engineering and Management, 148*(10), 04022110.

Wang, G., Liu, H., Li, H., Luo, X., & Liu, J. (2020). A building project-based industrialized construction maturity model involving organizational enablers: A Multi-Case Study in China. *Sustainability, 12*(10), 4029.

Wu, H., Qian, Q. K., Straub, A., & Visscher, H. (2019). Exploring transaction costs in the prefabricated housing supply chain in China. *Journal of Cleaner Production, 226*, 550-563. doi:https://doi.org/10.1016/j.jclepro.2019.04.066

Wu, P., Xu, Y., Jin, R., Lu, Q., Madgwick, D., & Hancock, C. M. (2019). Perceptions towards risks involved in off-site construction in the integrated design & construction project delivery. *Journal of Cleaner Production, 213*, 899-914.

Wuni, I. Y., & Shen, G. Q. (2020). Stakeholder management in prefabricated prefinished volumetric construction projects: benchmarking the key result areas. *Built Environment Project and Asset Management, 10*(3), 407-421.

Wuni, I. Y., Shen, G. Q., & Darko, A. (2022). Best practices for implementing industrialized construction projects: lessons from nine case studies. *Construction Innovation, 22*(4), 915-938.

Xu, Z., Zayed, T., & Niu, Y. (2020). Comparative analysis of modular construction practices in mainland China, Hong Kong and Singapore. *Journal of Cleaner Production, 245*, 118861.

Xue, H., Sun, T., Ling, F. Y., & Wang, L. (2023). Redesigning the virtual organisational structure for the management of prefabricated buildings. *International Journal of Construction Management, 23*(6), 1069-1085.

Xun, Z., Kang, L., & Zhao, Z. (2019). *Construction of prefabricated building supply chain operation model based on SCOR.* Paper presented at the IOP Conference Series: Materials Science and Engineering.

Yang, S., Hou, Z., & Chen, H. (2022). Network Model Analysis of Quality Control Factors of Prefabricated Buildings Based on the Complex Network Theory. *Buildings, 12*(11), 1874.

Yashiro, T. (2014). Conceptual framework of the evolution and transformation of the idea of the industrialization of building in Japan. *Construction Management and Economics, 32*(1-2), 16-39. doi:10.1080/01446193.2013.864779

Zhang, S., Li, Z., Li, L., & Yuan, M. (2022). Interface Management Performance Assessment Framework for Sustainable Prefabricated Construction. *Buildings, 12*(5), 631. Retrieved from https://www.mdpi.com/2075-5309/12/5/631

Zhang, Y., Lei, Z., Han, S., Bouferguene, A., & Al-Hussein, M. (2020). Process-oriented framework to improve modular and offsite construction manufacturing performance. *Journal of Construction Engineering and Management, 146*(9), 04020116.

Zhang, Y., Yang, Y., Pan, W., & Pan, M. (2021). *Key Performance Indicators of Offsite Construction Supply Chains: A Review.* Paper presented at the ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction.

Zhao, S., Wang, J., Ye, M., Huang, Q., & Si, X. (2022). An evaluation of supply chain performance of China's prefabricated building from the perspective of sustainability. *Sustainability, 14*(3), 1299.