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Rehan Masood and Krishanu Roy

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ABSTRACT

In the last three decades, prefabrication and offsite construction have gained wider attention across the globe. There have also been advances in prefabricated building technologies from a product perspective. However, no widely accepted classification system is available to help stakeholders develop their understanding of the prefabrication construction. This study reviews the recent prefabricated building technology classification systems in relation to the product type. Qualitative content analysis was performed to determine the development of the classification systems. Each prefabricated building technology type was reviewed in-depth for differences within classification systems. This study helps academics and practitioners to understand the basic differences amongst prefabricated building technologies, potentially leading to an increase in the uptake of prefabricated construction as stakeholders' knowledge of these technologies improves.

INTRODUCTION

Prefabricated building or construction is also termed offsite construction under the umbrella of modern methods of construction. Prefabrication originates from the 'manufacturing' domain and impacts the industrialisation of the construction process (Gann, 1996). This is an alternative to traditional construction with proven efficiency for productivity, efficiency, quality, safety and sustainability (Moradibistouni et al., 2018; Burgess et al., 2013) in all types of housing (Steinhardt & Manley, 2016; Masood & Lim, 2020). Furthermore, prefabrication has been considered the most suitable solution to improve affordability with an increase in the supply of house building stock (Masood et al., 2016). However, the adoption of prefabrication construction is still limited due to critical challenges, and stakeholders' perceptions is one of the top challenges (Masood et al., 2021). The integration of prefabricated building technologies (PBTs) in the project lifecycle context is more complicated from inception to execution (Pan et al., 2012). However, the early involvement of stakeholders is critical to exploit the benefits of PBTs (David et al., 2017) for residential and non-residential projects. Nevertheless, it is essential to develop a proper understanding of prefabricated construction for efficient and effective application on projects.

There is a plethora of terminologies used to define prefabrication which increases the complexity when developing a clear understanding of PBTs. The alignment of products, processes and supply chains entirely depends on how the client and stakeholder perceive the PBTs (Schoenwitz et al., 2017). The construction industry generally acts in silos and proper integration is not achievable. Similarly, 'innovation' does not have the same meaning for all stakeholders in supply chains. Perceptions about the different PBTs developed from considerations as to which was the best value for money, which in turn depended on the specific context of their use (Agapiou, 2021). Which PBTs are the most efficient depends on various factors and referring to any specific type is not particularly informative (Barlow et al., 2003). However, from a supplier perspective, PBT is viewed as a resource-based definition of the business strategy and portfolios (Goh & Loosemore, 2017).

PBT is linked with product technology, information technology and process technology which inter-relate with the products, people, and business processes (Nadim & Goulding, 2011). This interrelationship varies with the type of the prefabrication by product and material and shapes various business models for several types of houses and the engagement of stakeholders (Pan & Goodier, 2012). A recent review (Masood et al., 2022) on prefabricated house building showed that technology from a supply chain management perspective is also linked with integration, coordination, logistics, commitment, procurement, strategy, network, platform, project management, competency, power, outsourcing, contractors, marketing, sales, and partnership. This shows that PBTs have a substantial impact on the relational and managerial aspects from an organisational (supplier) and project perspective. In another study (Gan et al., 2022), PBT is linked with innovation, hierarchy, structure, development and research. This shapes the knowledge and understanding that PBT is integral in the offsite environment.

Two decades ago, Gibb and Isack (2003) defined the most basic categories of pre-assembly in the PBT context as component (C), non-volumetric (NV), volumetric (V), and modular (M). In project perspective, both C and NV are relatively good in performance, flexibility and innovativeness but V and MB are better in delivery, cost and quality (Jonsson & Rudberg, 2014). However, characterisation of the PBT is essential for its application in the industrialisation of buildings (Yashiro, 2014). PBTs have evolved, but to date, a clear understanding of PBT by stakeholders has still not been achieved, which shapes the knowledge and capability to implement on projects (Tookey, 2021a). This study aims to review the critical aspects of various PBTs to learn how the classification has developed and what the key variations are.

METHODOLOGY

This study uses qualitative content analysis to examine the latest approaches to classify the PBTs and report the key aspects. This review method is applicable in offsite construction literature reviews and provides an opportunity to explore the specific knowledge domain from a multi-perspective (Hu et al., 2019). The selected method is suitable to determine the key trends in defining the PBTs. There is inherent diversification in PBTs discipline-wise as key players in projects have different perceptions about the same PBT. However, the integration of practical knowledge is essential and depends on how well the PBT has been defined, understood and implemented (Pan & Goodier, 2012). To gain recent insight into PBT development and currency of the knowledge, only studies from the last five years were reviewed as no notable research was found to define PBTs. The articles were reviewed for their main approaches to developing the classification of PBTs, and further analysed by the basic types of PBT. The general approach covers the methodology and outcome of each article. Productivity was used as the main criterion to determine the variation amongst the different types of PBTs.

In Table 1, selected research studies, in descending order of publication year, are reported by title, method, and results.

S#	TITLE AND REFERENCE	METHOD	MAIN OUTCOME
1	Nomenclature for offsite construction (Lou et al., 2022)	Mixed research	Criteria for nomenclature
2	Development of an offsite construction typology: A Delphi study (Ginigaddara et al., 2022)	Mixed research	Offsite construction typology
3	Demystifying the concept of offsite manufacturing method – Towards a robust definition and classification (Ayinla et al., 2019)	Literature review	Offsite manufacturing classification by product, process and people
4	BIM in off-site manufacturing for buildings (Abanda et al., 2017)	Literature review	Ontology of offsite manufacturing concepts
5	Production system classification matrix: Matching product standardization and production-system design (Jonsson & Rudberg, 2015)	Case study	Classification Matrix

Table 1: Selected studies on the classification of PBTs.

RESULTS AND DISCUSSION

Studies on PBTs classification

Five key studies, published in the last five years, were selected to determine how the PBTs were classified in academic literature. Jonsson and Rudberg (2015) developed a revised classification matrix based on a case study approach by locating the appropriate PBTs based on the degree of offsite assembly and degree of standardisation. This study classified the PBTs as component manufacture and sub-assembly, prefabrication and sub-assembly, prefabrication and pre-assembly and modular buildings. The critical parameter is the degree of prefabrication and assembly which shapes various PBTs. Abanda et al. (2017) define the ontology of offsite manufacturing concepts developed from sub-assembly component, volumetric, panelised, modular, site-based and hybrid. This ontology was developed to integrate building information modelling in a prefabricated construction stream. This was a pioneer study to investigate the technological integration in buildings. This classification was a step towards systemic integration of PBTs with information technologies. Ayinla et al. (2019) developed an offsite manufacturing system based on products, processes and people. The product-based classification is categorised not only as prefabricated products but also as work sub-sectors, geometry configuration and materials. This study shows the interlinkage of PBTs with other domains. This study provides an extensive classification with coverage of processes such as procurement, production and assembly. This classification system integrates the managerial aspects of PBTs. Ginigaddara et al. (2022) define the typology of the offsite construction. The author categorised two types as non-volumetric and volumetric. In non-volumetric, components, panels and foldable structures were classified. However, in volumetric, there are pods, modules and complete buildings. This study attempts to simplify the PBT classification to avoid jargon. This study combines the strong integration of prefabricated construction with technological advancements with simple categorisation. Lou et al. (2022) investigate the nomenclature for offsite construction using a mixed research approach. Their study defined the criteria for nomenclature as uniqueness, informativeness, conformity, standardisation, relevancy, accuracy, extendibility, and conciseness which originate from physical, digital, construction and information quality. The rule of nomenclature is set on three layers of project code, with high-level component type, high-level component location, low-level component type, and differentiator as additional parameters. This study claims that with this nomenclature a balance between informativeness and conciseness, and also standardisation and extensibility will be achieved. This classification system includes the project dynamics and links with the level of complexity of PBT. All the classification systems address various critical aspects which help to understand the PBT on broader perspective with more clarity on diversifications. However, the classification systems' application in practice is essential which is mainly addressed in the fifth study reviewed (Jonsson & Rudberg, 2015).

Component-based classification (PBT_C)

This PBT demonstrates a low level of prefabrication as it is only focused on component manufacture and sub-assembly happens on site. In a particular building, there are several components which are sub-assembled onsite to shape larger components such as stick-built to wall or truss frames. These are also defined as floor cassette and roof cassette. PBT_C are structural and non-structural by work, and frame system by configuration. There is a problem identifying the specific component and assigning code as there are several components that are the same. However, a proper ordering system is essential from design to installation. This type of system allows high flexibility with pure customisation or tailored customisation which means changes can be made but it restricts the use of materials like steel which is less modifiable than timber. However, the productivity is comparatively low compared to the following PBTs.

Panel-based classification (PBT_P)

This PBT describes non-volumetric products which are prefabricated and sub-assembled partially onsite. PBT_P are many products but a limited number of each are used in housing as there is a clear difference in the offsite work needed considering logistics and cranage requirements. It is comparatively easy to identify the specific panellised unit and assign a code as there are limited numbers. However, a need for proper ordering system is essential from design to installation. When housing is built with panels, it is also called panellised construction. There are two main types of panellised construction – closed and open panellised units or systems. The closed panellised units require less amount of work onsite than the open units. Another term, "foldable structure", like floors, walls, and ceiling, was introduced which demonstrates the stacking and transportation of panellised units rather than "flat-pack." Examples under this classification are cross-laminated timber or structurally insulated panels, and precast concrete panels. PBT_P are building envelopes by work and planar systems by configuration. The PBT_P is suitable for tailored customisation and customised standardisation with high flexibility but low productivity.

Volume-based classification (PBT_V)

This PBT demonstrates volumetric products which are prefabricated and pre-assembled, with the least amount of work onsite which has a more installation focus. PBT_V are a limited number of products but many similar types which potentially cause identification and assigning issues in ordering from design to installation. PBT_V covers mainly bathroom pods used in both residential and non-residential construction. However, volumetric units or modules are also built which are used as part of a building, or the whole building is built with these units. PBT_V are building service by work which is repetitive due to similar design, and box system by configuration. The PBT_V is mainly suitable for customised standardisation with low flexibility but high productivity. This type of standalone PBT demonstrates the prefabricated construction is highly productive if it happens on a large scale.

Modular based classification (PBT_M)

This PBT describes modular products or buildings which are prefabricated, pre-assemble and pre-finished with the very least amount of work on site. PBT_M has one or a limited number of products but very many products of similar types. This type has the least issues in assigning codes for ordering as the whole building is well identified. PBT_M covers mainly whole houses or one stage of residential and non-residential construction. Transportable or relocatable houses are examples of this technology. PBT_P are special structures by work and box systems by configuration. PBT_M are less finished than PBT_V. Hence, there is still some amount of work to be done onsite such as final installation and fixing. Further, there is a risk of damage and a need for long distance transportation if the building is fully complete. The PBT_M is mainly suitable for pure standardisation with low flexibility but high productivity.

Hybrid based classification (PBT_H)

This PBT describes the combination of volumetric and panelised units. This classification comprises both characteristics of the volumetric and panelised systems with relatively the same productivity and flexibility. The PBT_H varies by a number of products and depends on the housing design solution. There is an opportunity to explore the degree of product standardisation within tailored customisation, customised standardisation, and segmented standardisation.

CONCLUSION

This study reports the critical aspects of classifications developed in research of offsite construction for types such as components, panels, volumetric and modular buildings. The classification for PBT has been commonly named from the matrix, (Jonsson & Rudberg, 2015), typology to nomenclature. The research approach in studies on classification has shifted from literature reviews to mixed research which helps to incorporate industry consultation. There has been substantial work to define the basics of the PBT classification but limited focus on the integration of classification systems with advanced technologies like Building 4.0. Work has also focussed on defining high and low prefabricated components rather than conventional types of PBTs. The PBT classification system has not reached maturity as there are still provisions to revise to align them with the advancements in PBTs. Further investigation of aspects which potentially impact the classification system will enhance the applicability and contextual relevancy. Recent classifications attempt to simplify the PBTs to clarify the technology system to better understand the prefabricated product application. There is less provision for hybrid prefabricated construction in the current classification systems. This study investigated the generalisation of the classification system and found that there is a lack of integration from theory and practice perspectives. Nonetheless, more emphasis is now on the practicability of the classification system, which will help the industry and academia align perceptions of the PBT.

In all PBT classifications, by definition, prefabrication and assembly are dominant factors. Further, the frequency and similarity of by-products is also considered a significant differentiator. Possible usability, work assignment and configuration of each PBT also creates a clear demarcation. Nonetheless, the comparison of productivity and flexibility is still valid for the PBT classification system. Each PBT has potential to enhance the project's performance but several aspects should be considered. There is a need to address the classification system to cover transportation and on-site assembly which also share the key performance criteria (Grenzfurtner et al., 2022).

In a recent industry survey (Tookey, 2021b), a decline has been observed in the pod and modular construction in New Zealand, which suggests serious efforts should be taken by the government, academia and industry in promoting the uptake of PBTs. Government should consider the inherent diversification of the PBT system for developing housing policies, such as which PBT is suitable for medium-density housing. Understanding the classification system is helpful in the development of skills and qualifications for offsite construction workforce. The robust classification system helps practitioners decide which specific PBT system to implement on projects. Nonetheless, this study gives an overview of the classification for PBTs reported in the literature and what are the key dynamics and development trends towards a better understanding of prefabricated construction.

Rehan Masood is an experienced academician and is currently involved in the delivery of civil engineering, construction, quantity surveying and project management courses. His current research is related to construction education, offsite construction, supply chain management, and building information modelling. He gained NZ based industry affiliations such as NZIOB, PrefabNZ and EngNZ.

https://orcid.org/0000-0002-6886-2163

Krishanu Roy is a Senior Lecturer in Civil Engineering at the University of Waikato. He is teaching Advanced Civil Engineering Design Challenge, Advanced Construction Technologies, Civil Design Challenge 2 and Structural Steel Design. His research interests are fire performance of cold-formed steel structures, application of Artificial Intelligence and Machine Learning for the structural prediction of cold-formed steel members, sustainability and life cycle analysis of structures.

https://orcid.org/0000-0002-8086-3070

REFERENCES

Abanda, F. H., Tah, J. H. M., & Cheung, F. K. T. (2017). BIM in off-site manufacturing for buildings. *Journal of Building Engineering, 14*(Supplement C), 89–102.

Agapiou, A. (2021). An exploration of the best value perceptions of small housebuilding developers towards offsite construction. *Sustainability, 13*(7), 4054.

Ayinla, K. O., Cheung, F., & Tawil, A.-R. (2019). Demystifying the concept of offsite manufacturing method—Towards a robust definition and classification system. *Construction Innovation, 20*(2), 223–246.

Barlow, J., Childerhouse, P., Gann, D., Hong-Minh, S., Naim, M., & Ozaki, R. (2003). Choice and delivery in housebuilding: lessons from Japan for UK housebuilders. *Building Research & Information, 31*(2), 134–145. https://doi.org/10.1080/0961321030200 3

Burgess, J. C., Buckett, N. R., & Page, I. C. (2013). *Prefabrication impacts in the New Zealand construction industry in study report 2013*, Building Research Association New Zealand (BRANZ), Auckland, New Zealand.

David, F., Ameer, A. N., & Kenneth, P. (2017). Enhancing off-site manufacturing through early-contractor involvement (ECI). *Proceedings of the Institution of Civil Engineers— Management, Procurement and Law 0*(0), 1–35.

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

Gan, X.-L., Xie, K., Liu, H., Rameezdeen, R. and Wen, T. (2022). A bibliometric and content analysis of policy instruments on facilitating the development of prefabricated construction in China. *Engineering, Construction and Architectural Management* (ahead-of-print). https://doi.org/10.1108/ECAM-01-2022-0044

Gibb, A. & Isack, F. (2003). Re-engineering through pre-assembly: client expectations and drivers. *Building Research & Information, 31*(2), 146–160.

Ginigaddara, B., Perera, S., Feng, Y., & Rahnamayiezekavat, P. (2022). Development of an offsite construction typology: A Delphi study. *Buildings, 12*(1), 20. https://doi.org/10.3390/buildings12010020

Goh, E. & Loosemore, M. (2017). The impacts of industrialisation on construction subcontractors: a resource based view. *Construction Management and Economics, 35*(5), 288–304.

Grenzfurtner, W., Rudberg, M., Mayrhofer, R., Loike, K., & Gronalt, M. (2022). Performance measurement and management practices of on-site activities in industrialised housebuilding. *Construction Management and Economics, 40*(4), 239–253. https://doi.org/1 0.1080/01446193.2022.2037147

Hu, X., Chong, H-Y., & Wang, X. (2019). Understanding stakeholders in off-site manufacturing: A literature review. *Journal of Construction Engineering and Management, 145*(8), 03119003. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001674

Jonsson, H. & Rudberg, M. (2014). Classification of production systems for industrialised building: a production strategy perspective. *Construction Management and Economics, 32*(1–2): 53–69.

Jonsson, H. & Rudberg, M. (2015). Production system classification matrix: Matching product standardisation and production-system design. *Journal of Construction Engineering and Management, 141*(6), 05015004.

Lou, J., Lu, W., & Xu, J. (2022). Nomenclature for offsite construction. *Building Research & Information*, 1–15. https://doi.org/10.1080 /09613218.2022.2039586

Masood, R., Lim, J., & González, V. (2016). A taxonomy of construction supply chain for affordable housing in New Zealand. *International Journal of Structural and Civil Engineering Research, 5*(1), 16–21.

Masood, R., & Lim, J. B. P. (2020). MDH with prefabricated cold-formed steel. *NASH News*. National Association of Steel Housing: Auckland.

Masood, R., Lim, J. B. P., and González, V. A. (2021). Performance of the supply chains for New Zealand prefabricated house-building. *Sustainable Cities and Society*, 102537. 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. https://doi.org/10.3390/buildings12010040

Moradibistouni, M., Vale, B., & N. Isaacs. (2018) *Prefabrication: New Zealand manufacturers of prefabricated buildings and components 2017*. In *52nd International Conference of the Architectural Science Association*. Melbourne, Australia. The Architectural Science Association and RMIT University.

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.

Pan, W., Gibb, A. G. F., & Dainty, A. R. J. (2012). Strategies for integrating the use of off-site production technologies in house building. *Journal of Construction Engineering and Management, 138*(11), 1331–1340.

Pan, W. & Goodier, C. (2012). House-building business models and off-site construction take-up. *Journal of Architectural Engineering, 18*(2), 84–93.

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. https://doi.org/10.1016/j.ijpe.2016.10.015

Steinhardt, D. A. & Manley, K. (2016). Adoption of prefabricated housing–the role of country context. *Sustainable Cities and Society, 22*, 126–135.

Tookey, J. (2021a). *Prefabricated construction in New Zealand: Education, skills and attitudes survey*. Offsite NZ: Wellington.

Tookey, J. (2021b). *Prefabricated construction in New Zealand: Current status and underlying trends*. Offsite NZ: Wellington.

Yashiro, T. (2014). Conceptual framework of the evolution and transformation of the idea of the industrialisation of building in Japan. *Construction Management and Economics, 32*(1-2), 16–39.