Islam, M., Bunster, V., Couper, R., Jalali Yazdi, A. & Maxwell, D. (2024). Process modularity – a lean approach to develop industrialised building platforms. In D. B. Costa, F. Drevland & L. Florez-Perez (Eds.), *Proceedings of the 32nd Annual Conference of the International Group for Lean Construction* (IGLC32) (pp. 894–905). doi.org/10.24928/2024/0208

PROCESS MODULARITY – A LEAN APPROACH TO DEVELOP INDUSTRIALISED BUILDING PLATFORMS

Mohaimeen Islam[1], Victor Bunster[2], Rachel Couper[3], Alireza Jalali Yazdi[4] and Duncan Maxwell[5]

ABSTRACT

The concept of modularity within product platforms and lean thinking has drawn attention in recent years, to achieve a balance between standardisation and customisation in industrialised building (IB). Modularity plays an important role in IB, where companies use standardised modules on common platforms for product development. Although the application of product modularity is widely discussed in the literature, the concept of modularity is not fully explored as a mechanism for process development, aiding to improve cost efficiency, quality and coordination across the IB value chain. Previous research within lean construction emphasises the importance of modularity in both product and process dimensions. However, a lack of clear understanding has impeded the full adoption of process modularity in IB platforms.

This paper examines the work processes of a Japanese case company to identify modular patterns in the technical systems for varied house production. By analysing qualitative data, the findings present potential advantages of modularity in the case company's lean approach to standardise the design, production, assembly and logistics processes. The study contributes in presenting a concept of process modularity to support developing process platforms in IB.

KEYWORDS

Process modularity, industrialised building, lean construction, platforms, technical system

INTRODUCTION

Industrialised building (IB) is seen as a means for streamlining building processes and promoting efficient and cost-effective activities to reduce resource waste (Björnfot & Stehn, 2004). IB comprises various constructs that require integration and continuous development to enhance productivity, product variety and quality through product and process predefinition (Lessing, 2006, 2015). This approach aligns with the concept of lean construction that defines a methodology for work structuring, aiming at streamlining the whole construction process across design, production and assembly (Ballard *et al.*, 2001a; Koskela *et al.*, 2002). Recent studies suggest that such efficiency has been achieved by a number of IB companies through

[1] PhD Candidate, Future Building Initiative-MADA, Monash University, Australia, mohaimeen.islam@monash.edu, orcid.org/0000-0001-6322-6697

[2] Lecturer, Department of Architecture, Associate Director, Future Building Initiative-MADA, Monash University, Australia, victor.bunster@monash.edu, orcid.org/0000-0002-7665-4567

[3] Lecturer, Department of Architecture, Future Building Initiative-MADA, Monash University, Australia, rachel.couper@monash.edu, orcid.org/0000-0002-3762-7996

[4] Postdoctoral Research Fellow, Future Building Initiative-MADA, Monash University, Australia, mani.jalaliyazdi@monash.edu, orcid.org/0000-0002-4419-9504

[5] Director, Future Building Initiative-MADA, Monash University, and Research Program Lead, Building 4.0 CRC, Australia, duncan.maxwell@monash.edu, orcid.org/0000-0002-9039-1441

the adoption of a product platform approach (Jansson, 2013; Jensen *et al*., 2013; Johnsson, 2013; Thuesen & Hvam, 2011). Originating in manufacturing, a product platform is defined as "the collection of assets (i.e., components, processes, knowledge, people and relationships) that are shared by a set of products" (Robertson & Ulrich, 1998, p. 20).

Hvam *et al*. (2008) contributed to platform-related research by examining varying degrees of pre-engineering in four production strategies: Engineer-to-Order (ETO), Modify-to-Order (MTO), Configure-to-Order (CTO) and Select-Variant (SV) (Figure 1). At the lowest level – ETO strategy, traditional project-oriented norms and standards predominantly define pre-engineering. MTO involves increased use of standardised technical solutions. CTO employs predefined parts, components, and modules for building configuration, while SV involves the pre-definition of entire buildings with minimal project-specific solutions (Hvam *et al*., 2008). ETO and MTO strategies typically result in increased flexibility in traditional building production, with project-specific solutions. On a contrary, in CTO and SV strategies, limited flexibility in product offerings allows high levels of platform predefinition, where modularity plays an important role in product and process standardisation (Gosling & Naim, 2009; Johnsson, 2013; Lessing & Stehn, 2019). Extending this concept, Johnsson (2013) suggests that the dominant production strategy in construction is ETO, which allows different settings for the utilisation of platforms in house-building: design-to-order, adapt-to-order, and engineer-to-stock. By utilising an adapt-to-order structure – a subset of ETO, components of the design solution are pre-engineered, and the final product is achieved by assembling these pre-engineered parts. According to Johnsson (2013), such a strategy allows standardising and modularising processes along with the products.

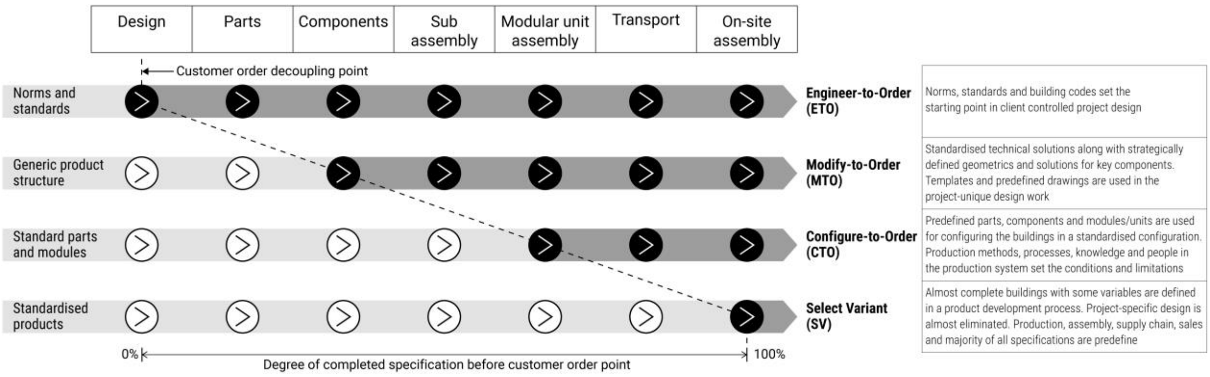

Figure 1: Four platform strategies in construction. Figure 1 adapted from Hvam *et al*. (2008)

Although modularity as a concept has received considerable interest among academics and practitioners, for product standardisation, there has been less research on the aspect of modularising IB work processes. Johnsson (2011) underscores the significance of standardising technical systems as strategic assets across the IB value chain. This involves structuring building activities, rules and decisions as process modules (Lessing, 2006; Lidelöw *et al*., 2015). The paper argues that these process modules have common attributes enabling their flexible rearrangement and interchangeability across multiple projects.

Reviewing the literature on modularity, lean thinking and technical systems as a basis, this study explores existing approaches to modularising work processes in IB. Empirical data are gathered from a Japanese case company and include live observation and document analysis, where the house design-to-production process and platform application were examined based on lean thinking. The aim is to analyse the technical systems across the IB value chain to evaluate the approach in modularisation, reuse and scalability of processes in varied projects. The analysis identified modular patterns within the case company's technical systems across the design, production, assembly and logistics workflow, including relationships between actors, activities, and assets. From the evaluation of the findings this paper presents an understanding of the concept of process modularity from a lean perspective. Such an understanding of modular building processes is useful for developing IB process platforms and identifying opportunities for future research on this topic.

LITERATURE REVIEW

MODULARITY

Modularity has been an important topic within engineering literature and it refers to the structure of a product or process that comprises smaller subsystems (i.e. chunks or modules), and is managed independently, yet can perform together holistically (Baldwin & Clark, 1997; Ulrich, 1995). A module is perceived as a self-contained unit with its own functionality and standardised interfaces that interact based on the systems' definition. (Miller & Elgard, 1998). From a product design perspective, such independence of module development allows a company to standardise components and create product variety, with minimal impact on production. These concepts view modularity as a product development strategy, utilising a product platform approach (Simpson, 2004). In the construction context, modularity is frequently viewed through a product lens, referring to the utilisation of basic building blocks (Rampersad, 1996). Furthermore, research in construction on production systems and pre-engineering approaches (i.e. ETO, MTO, CTO, SV) have left modules with a rather narrow role as highly standardised volumetric units (Jonsson & Rudberg, 2014).

Nevertheless, modularity influences not just the architecture and structure of products but also the organisation and processes involved in their design and production (Baldwin & Clark, 1997; Fine, 1998). A modular process becomes significantly useful when a system becomes so large that interdependence between physical components for integrated design and production becomes difficult (Rocha & Koskela, 2020). Fine (1998) argues that the level of modularity present in the final product aligns directly with the level of modularity in the construction processes and supply chains. Fine's claim consequently presents three perspectives of modularity – product, process and supply chain modularity. In light of these insights, this paper aims to explore the concept of process modularity, shifting focus from mere product-driven considerations towards reshaping and streamlining organisational structures and supply chain dynamics to enhance adaptability and efficiency in IB.

PROCESS MODULARITY

The building process involves project-specific work activities that are often not pre-defined (Knotten *et al.*, 2015). These activities result in highly varied combinations of workflows for each project (Sibenik *et al*., 2022). Sibenik *et al*. (2022, p. 1) argue that single activities within the building workflows "are similar and constitute patterns that could allow for modularisation and eventual standardisation." According to Sibenik *et al*., identifying modular patterns becomes possible when building processes are divided into shorter processes or subprocesses as work activities. A modular process enables the use of shared production system, parallel assembly, along with standardised manufacturing, delivery, and assembly activities (Lennartsson & Björnfot, 2010; Peltokorpi *et al*., 2018). Lennartsson and Björnfot (2010) refer to this approach as process modularity, which is concerned with standardising building operations with shared interfaces. In IB, such standardised building operation means to utilise a set of technical solutions and processes for varied product developed, i.e design decisions, planning methods, component and interface configuration, workflows, supply chain logistics, production systems etc., across the entire building value chain (Lessing, 2006, 2015). Building on this, Peltokorpi *et al*. (2018) emphasise the process asset within the product platform definition. In their view, platform assets contributing to enhanced outcomes in IB are not necessarily standard components but rather standardised processes for manufacturing, preassembling, delivering, and assembling components on-site. These concepts relate to Bjornfot & Stehn's (2004) claim that process modularity effects in the IB value chain can be examined through the following criteria (Table 1):

Table 1: Effects of process modularity in IB. Table 1 adapted from Bjornfot & Stehn (2004)

Development of new modules	Its approach to the development of new modules with standardised processes
Allowing external variety	Its approach for minimising internal complexity and enhancing external variety
Production optimisation	Its strategy for designing and using standardised products and processes to achieve optimised production
Reusability and reconfigurability	Its approach to reuse standardised processes while recycling and reconfiguring modules to develop differentiated end products

In achieving these modularity effects, Bjornfot & Stehn suggest two strategies for viewing the construction process: top-down or bottom-up. The top-down view looks into streamlining processes by implementing lean thinking. It relates to the production system of new products that are volume-based, often caters for end customers' needs and allows the reusing of previous processes and technologies (Björnfot & Stehn, 2004). On the contrary, in the bottom-up view, the design of the product and the unique needs of end customers guide the production processes. This is more relevant to an ETO-based strategy in project-specific construction (Koskela, 2003). In lean terms, the top-down approach is suitable for CTO-based IB companies to achieve both product and process value, leveraging modularity and reusability of building processes.

Lean thinking

As previously discussed, modularity of processes can optimise the entire building workflow from design through production, assembly and delivery of the completed building. This relates to lean thinking, where the primary goal is the elimination of waste and the creation of value (Green, 1999). The term "lean" stems from the Japanese manufacturing industries as "Lean Manufacturing (LM)", where the aim is to optimise the value stream in mass production (Ballard *et al*., 2001b; Koskela, 1997; Womack & Jones, 1997). In the building industry, the concept is called "Lean Construction," aiming at improving site-level production, as well as increasing the value delivered to the customers (Ballard & Howell, 1994). Bjornfot & Stehn (2004, p. 6) define lean construction as "a process management discipline offering management during the whole construction process, aiming at streamlining production."

In lean construction, the organisation of production is referred as work structuring (Ballard *et al*., 2001a; Koskela *et al*., 2002). In this manner, applying modularity of processes leads to achieving lean construction principles, as it allows work structuring to reduce complexity and waste from design-to-completion stages in IB (Bertelsen, 2005). Bertelsen (2005) argues that modularisation allows an efficient construction process, asserting that such an approach is lean as it minimises customer influence on design while enhancing product quality and process flow. Lidelöw *et al*. (2015) further highlight that process modularity can support knowledge innovation and the breakdown of activities, helping to structure work processes through the interdependencies between them. Such work structuring relates to developing and reusing technical systems as a way to improve the IB platform strategy (Jansson *et al*., 2015).

Technical system

Within the concept of lean construction, the approach to streamlining the complex IB processes and modularising workflows entails standardising technical systems as strategic assets across the building value chain (Johnsson, 2011). Technical systems involve not only defining product configuration but also a set of rules, instructions and guidelines that govern the design, installation and operation of those building systems (Lidelöw *et al.*, 2015). Standardising technical systems means analysing building activities and decisions to optimise all stages of the building processes with a focus on reusability across diverse projects. In analysing technical systems, information is partitioned into visible rules – comprising architecture, interfaces and standards. Architecture describes the modules that are part of the applied building system, whereas interfaces describe interactions between the modules, and standards govern how the modules are functioning in the system (Baldwin & Clark, 1997). In this relation, building systems relate to physical component configuration and are generally categorised into five types (Figure 2): site, structure, skin/enclosure, services, and space including furnishing and fixtures (Smith, 2010). According to Johnsson (2011), the choice of a building system defines not only what technical systems are required for standardisation, but also the organisation within the company, its market position and future growth.

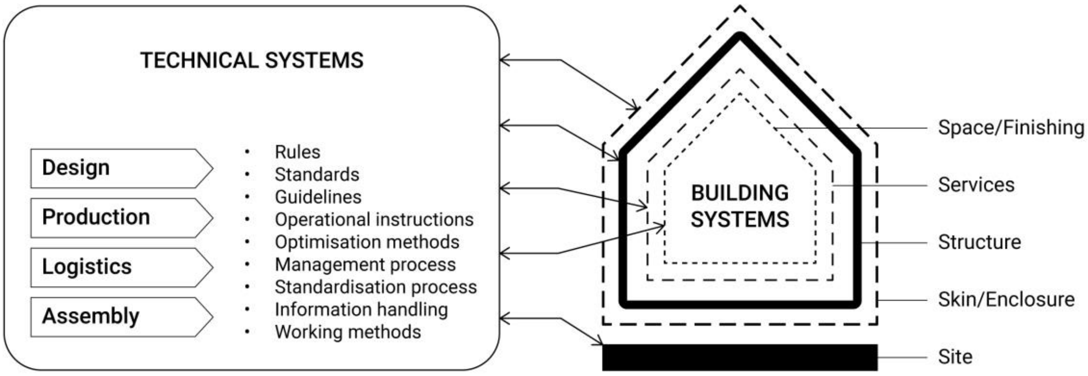

Figure 2: Relationship between technical systems and building systems in IB. Figure 2 adapted from Smith (2010)

Lessing (2006) includes a process model for IB that is supported by a technical and process platform. The process model emphasises the significance of technical systems in IB platform development. The technical systems include structural frames, installations, façade, roof systems etc., and are used for configuring complete buildings. According to Lessing, a technical platform configures technical solutions: establishing standards, and developing technical systems suitable for effective production, transportation, and assembly of building components; whereas the process platform involves a systematic collection of instructions and organisation of process modules concerning collaboration, design, planning, production and logistics methods, information handling systems etc. (Lessing, 2006, 2015). Lessing's (2006, 2015) concept of utilising technical systems, however, relates to the product side, concerning the configuration of building systems. However, building on the earlier literature, it can be argued that developing technical systems is not limited to standardising physical configurations of building systems and rather requires structuring associated work activities (i.e. workflows, collaborative decisions among different stakeholders, design, production and assembly methods etc.). In this manner, the modularisation of technical systems requires an efficient process platform to allow work structuring across the IB value chain. In Lennartsson and Elgh's (2018) view a properly developed process platform should facilitate structuring technical systems and enable lean practice both in design and production in IB. In this paper, the concept and implication of modularity are tested by analysing the building processes of a case company that enables a lean approach in their platform application.

RESEARCH AIM AND METHOD

This paper aims to understand the modular patterns, concerning work activities, actors, and assets, across the design-to-production phases, to evaluate the effects of process modularity

(Sibenik *et al*., 2022). To achieve this aim, a Japanese IB company (named in this paper as "H") was studied by mapping their technical systems as design and production interfaces. The company was chosen due to its extensive application of lean construction while meeting customers' requirements during house production. A visit to the factories of case company H was organised to observe the design, prefabrication, assembly and logistics processes of their varied modular house products. Through a Case Study Research (CSR) method, qualitative data concerning design and production processes, technical systems, supply chain management, working methods, knowledge resources, product and platform development strategies were captured and also through studying the supplied documents, i.e. drawings, reports etc. CSR is useful for studying a phenomenon in its natural context, as it enables the comparison of different theories and observations from empirical data (Miles & Huberman, 1984). In this method, a qualitative approach to collecting empirical data provides an opportunity to obtain a sufficient level of detailed information (Gummesson, 2000). While assessing the company's technical systems and platform strategy the research seeks to respond to the following questions:

1. Are there any recognisable modular patterns in the technical systems of the IB company?
2. How process modularisation strategies are currently utilised in the technical systems to support the development of a process platform?

Through the observations and documentation, and the analysis of the captured data, this study a) identifies modular patterns within the case company's technical systems across the design, production, and assembly processes, b) suggests a concept of process modularity that supports the development of an efficient process platform, and c) presents an opportunity for conducting future research on process modularity from a lean perspective.

CASE DESCRIPTION

The studied company has been a market leader in factory-built residential housing in Japan since the 1970s. The company manufactures volumetric houses across eight strategically located factories in Japan. These facilities utilise highly automated systems for the production of a variety of standardised components, aiming to attain greater economies of scale. The company applies a platform-based IB strategy for component production, with up to 80% - 85% of final production completed on the factory's automated assembly lines. The company utilises standardised building systems such as façade systems, building frames, wall and floor panels, and modular interfaces across a wide variety of project types to enable non-repetitive and unique product offerings. A lean modular approach has allowed the company to work towards optimising the entire building process, achieving an efficient flow of projects across multiple production lines. The building system is based on volumetric blocks, utilising both steel and timber-frame volumetric units. The system is defined as a Unit Method, where the functional spaces are produced as units and then several units are assembled on-site using standardised interfaces. The company is vertically integrated, incorporating sales, design, production, construction, after-sales, servicing and remodelling - all under the same organisation.

BUILDING PROCESS

This section presents an analysis of the collected qualitative data providing an overview of the product development process across the design-to-assembly stages for various house products. These findings are synthesised in the next section to discuss modular patterns that are identified.

The house product developed by the case company incorporates product families, building systems and previous house models. Most units, accounting for 80 per cent, are constructed with light gauge steels, while the remaining 20 per cent are built using light wood frames. In the factory, light gauge steel frame units, acting as "chassis", undergo customisation according to customer specifications, and serve as the primary structural support. The top factory floor fabricates the chassis while the bottom floor applies external & internal finishes, internal fit-outs, cables, pipes and indoor sub-components such as stairs, cabinetry and other equipment, with a just-in-time approach. The company has developed 6 basic house types, which can be customised using 70 types of units, including 40 standard cuboids available in 10 different lengths, 2 heights, and 2 weights, while the rest are uniquely shaped units, like trapezoids. Square steel tubes are used in different sizes for different applications, including: (i) 100 to 120mm tubes for posts, (ii) 200mm tubes for the beams, and (iii) 150mm non-flexible tubes for the floor beam. Typically, 10 to 15 of these steel-framed volumetric units, adjusted based on the house size and customer demands, are assembled to construct a two-storey family house with an approximate floor area of 130-150 sqm. For manufacturing efficiency, the units are designed for transportable dimensions, typically measuring 1.8 - 5.4m in length (nine standard lengths), 2.5m in height, and 2.4m in width. Moreover, the company provides units in half-sized dimensions for each measurement and also uses partitions at fixed 900mm intervals.

While configuring units for varied house types, the exterior and interior finish combinations vary (compound panels, composite panels with pre-attached veneers, aluminium plates, gypsum boards, etc.); so do roof styles (flat, sloping etc.), stairs, kitchen and bathroom fittings, plumbing fixtures, and light-switch locations. An average house contains approximately 30,000 distinct component types out of a vast selection of over 300,000 available options. The IB company also created an Open Engineering System (OES) that possesses the capacity for further development or transformation into new product models. For production efficiency the company employs a two-part order system, each unit divided into parts, prepared to basic standard specifications (concerning frames, floor, wall, and ceiling panel etc.) and standardised options (i.e. colour and finishes). Upon receiving a customer's order, the sales company drafts the floor plan and passes it on to the factory point with component specifications. A computer-controlled production management system handles received data necessary for diverse component assembly on the 400-meter production line. Constructing a house within the factory typically takes about three hours. It starts with cutting steel components for framing the units and progresses through the zinc coating process. This includes frame fabrication, including robotic automatic arc welding of ceiling and flooring elements to form a skeleton. After the welding process, the steel frame chassis progresses through the conveyor belts and receives finishing touches across more than 50 workstations. Workers proceed to install all essential panels, windows, doors, staircases, services, bathroom and kitchen units, and fittings according to work schedules. In this step, varied suppliers deliver materials, parts, components, and prefabricated sub-systems (such as bath and kitchen units) just-in-time and just-in-sequence through the gates placed on both sides of the assembly lines. Installation of external cladding, electro-mechanical services and plumbing are conducted in the next stage. At the final workstation, some units are stored and others are prepared for delivery. The on-site tasks encompass site preparation (2-3 weeks), assembling units, immediate weatherproofing, airtightness and connecting to utilities (1-3 days). After the initial assembly, additional work including minor interior and exterior finishing is completed within a month. To maintain quality and 100% error-free product handover, rigorous inspections occur post each production step. The stringent factory processes, supported by lean principles lead to decreased failure rates while improving the overall quality and long-term reliability of the building products. Figure 3 shows the streamlined design-to-assembly workflow for house production by the case company.

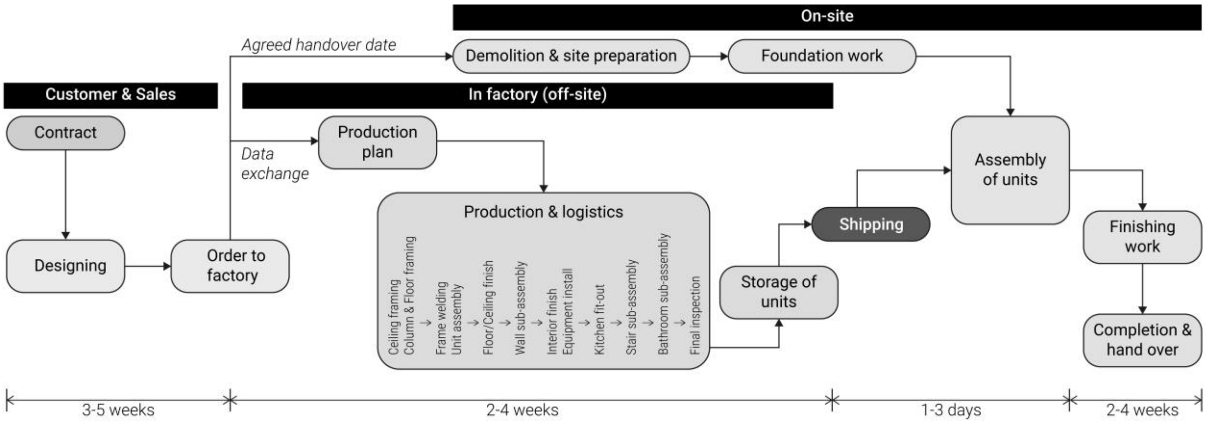

Figure 3: Standardised design-to-assembly work processes by the case company.

DISCUSSION

The case company presents a top-down view from a lean modular perspective to streamline processes (Björnfot & Stehn, 2004). This allows for reusing previous processes and technologies, achieving economies of scale. In this sense, the company adopts an adapt-to-order subset of ETO strategy as referred by Johnsson (2013) in developing its product platform with pre-engineered solutions. By applying such a strategy, the company responds to the individual demands for housing solutions while enabling modularised processes, product architectures, and supply chains. The platform assets (components, processes, knowledge, people, and relationships) described by Robertson & Ulrich (1998) are well-established in the case company through (1) a modular structure of the product - Unit Method, (2) a well-described technical system across design-to-production process, (3) technical know-how and reusability of knowledge, and (4) a well-managed supply chain and logistics system. Referring to Lessing's model, the interchangeability and reusability of the work processes (e.g. collaboration, design, planning, production and logistics methods, information handling systems) support the development of an efficient process platform by H. Building on Bjornfot & Stehn's (2004) concept, the analysis of the collected data identifies process modularity patterns as follows:

Development of new modules: The Open Engineering System (OES) developed by the company, based on parameters, enables the direct translation of customers' desired floor plans into production sequences, logistics, and work tasks. This reflects a lean approach to streamline the design-to-production processes. This innovative system has the potential to create new platforms and product variants using existing components and reconfigure building processes for new house production.

Allowing external variety: The houses made by H are assembled from several volumetric units. These room-sized units offer variety in the room layout, house shape, roof type, kitchen and bathroom pattern, materials, colours, finishing, fixtures, and fittings. By accommodating these varieties of standardised options, the units are customisable, allowing distinctiveness from each other. Moreover, the interfaces of the components and units are also standardised, reducing internal complexity while increasing external variety. Table 2 presents a synthesis of how standardised components are used to allow a certain level of customisation in the case company's varied house production.

Table 2: Standardised components by company H allowing customisation options

Standard components	Modular product architecture, allowing customisation	
Steel frames	n/a	100-120mm tube for posts, 150-200mm tube for beams
Room units	Dimensions	10 to 15 units: 1.8 - 5.4m in length (nine standard lengths), 2.5m in height, and 2.4m in width
Wall, Floor and Roof panels	Dimensions & finishes	900mm intervals and half-sized measurements
MEP work	n/a	
Fixtures, Fittings, Finishing	Choice	Approx. 30,000 component selections from 300,000 options
Paintwork	Colour Choice	
Joining interfaces	n/a	

Production optimisation: The production process follows a lean modular approach in terms of value flows across a sequence of 50 workstations, with a focus on process optimisation in each step. The standardised interfaces of the house parts allow interchangeability of the production process for six different house configurations across the six parallel production lines. The planning, production rate and transportation sequence for these components and units are predefined and support a repetitive process strategy. Table 3 presents the modular patterns that are observed across six parallel production lines for six basic house designs:

Table 3: Modular patterns observed in varied house production by company H

Common steps	Modular patterns in the work processes
1. Customer order and design	[3-5 weeks] The involvement of customers in the design process using a CAD system is modular and reusable across multiple house productions.
2. Data transfer for order entry	[1-2 hours] Modular patterns in design involve 80% predetermined parts and 20% custom parts, with a factory order system for component selection.
3. Conversion of design to objects	[1 day] The automated conversion of design data into objects and BOM, along with weekly batched production plans are modular and standard for all projects.
4. Unit production	[1-2 weeks] The production sequence on six assembly lines is modular, with predefined tasks, and standardised and interchangeable components.
5. Site preparation	[2-3 weeks] The procedure for site preparation (including demolition and recycling of old materials) follows a modular pattern across all projects
6. Delivery and assembly	[2-4 weeks] Modular activities on-site assemble units in 1-3 days, including weatherproofing and airtightness, optimizing completion timeline in 20-30 days.

For production optimisation, the company employs a parameter-based system that helps to modularise the entire workflow encompassing design, configuration, planning, order reception, logistics, fabrication, and delivery. Furthermore, modular work patterns are also evident in production checks by inspectors at different stages for quality assurance, using a system of green, yellow, and red demarcations of defect rates. Yellow suggests required corrective action; red means unacceptable defects. All processes follow the same modular pattern, however, depending on the house product type, the duration could differ for each of the steps.

Reusability and reconfigurability: The manufactured units developed by the company are not project-specific, and can be used interchangeably in a range of house products. This allows the reuse of a considerable proportion of technical systems, pertaining to the design, production, assembly, disassembly and recycling of the units for a completely new building. The technical systems work as a knowledge repository for process modularisation, allowing for the realisation of an efficient process platform. Moreover, the company relies on long-term relationships with numerous suppliers (approximately 200) for key product components, supported by a modular supply chain structure. In reference to Jansson's (2013) claim, in this case, experience feedback from the supply chain is utilised in the platform, a strategy that follows the principles of lean thinking, where long-term strategy and holistic view are the keys. From this perspective, process modularity is closely related to the degree of vertical integration.

To summarise, the IB company H has developed modular production processes, including a well-defined modular production facility and a modular supply chain structure. Standardised work activities and experience feedback support the development of an efficient process platform to optimise building processes across the entire value chain. The long-term benefits of defining, streamlining and refining activities by experience feedback follow the perspectives of Koskela *et al*. (2002), Bjornfot & Stehn (2004), and Bertelsen (2005) on lean thinking, as discussed in the literature review section.

CONCLUSION

This paper explores the concept of process modularity and its potential to drive lean construction in IB companies. The research comprises qualitative analysis on a Japanese case company, recognising their modular work patterns and how their application of a platform-based approach enables process modularity across different stages including design, production, and assembly. Previous studies have identified the concept of modularity in product, process and supply chain dimensions, however, a clear understanding and application of process modularity is missing in an IB context. This study argues that analysing IB work activities for repetitive patterns creates the base for process standardisation, ultimately leading to process modularisation, and in turn creating the conditions for increased lean construction.

In response to the research questions, this paper first conducted a literature review to establish an understanding of relevant concepts such as modularity, platforms, lean thinking and technical systems in an IB context. Then the effects of modularity on technical systems was examined, including work processes, actors and assets, through a qualitative analysis of the observations and extracted data from the building processes of the Japanese IB company H. Through evaluation of the case study analysis this research contributes by –

1. identifying a set of modular patterns in the IB value chain that supports the technical systems involved in the development of volumetric units;
2. mapping a flow of standardised activities that are common across house products; and
3. presenting a concept of process modularity that allows reusing technical systems, supporting lean principles, and enabling the realisation of an efficient process platform.

However, the findings from the case study suggest the applicability of modular processes in an adapt-to-order subset of ETO context, where the IB company is vertically integrated. The wider scope of modularising technical systems requires further examination in other platform contexts, i.e. ETO in general and MTO, to broaden the concept of process modularity in lean construction. Also, the dependency of the work activities and the amount of allowable deviation for interchangeability of process modules are not fully explored. Moreover, the boundaries of the level of modularity of work activities are not clearly defined, which presents future research opportunities in this area. Nevertheless, the evaluation of the case study may offer future guidelines for similar IB companies who intend to implement a platform strategy where modularity of process enables an efficient process platform. Owners, designers and developers may be benefitted from this case study findings to determine how work processes could be structured and modularised to develop their technical systems, and what kind of platform strategy would best support the modularisation effects to benefit from process modularity in IB.

REFERENCES

Baldwin, C. Y., & Clark, K. B. (1997). Managing in an age of modularity. *Harvard business review*, *75*(5), 84-93.

Ballard, G., & Howell, G. (1994). Implementing lean construction: stabilizing work flow. Proceedings of the 2nd Annual Meeting of the

International Group for Lean Construction, 12–14 September 1994, Santiago, Chile.

Ballard, G., Koskela, L., Howell, G., & Zabelle, T. (2001a). Production system design in construction. 9th Annual Conference of the International Group for Lean Construction, National Univerdity of Singapore.

Ballard, G., Koskela, L., Howell, G., & Zabelle, T. (2001b). Production system design: Work structuring revisited. *LCI White Paper*, *11*, 1-14.

Bertelsen, S. (2005). Modularization–a third approach to making construction lean. Proceedings of 13th International Group for Lean Construction (IGLC) Conference, Sydney, Australia.

Björnfot, A., & Stehn, L. (2004). *Industrialization of construction : a lean modular approach* 12th Annual Conference of the International Group for Lean Construction, 3-5 August 2004, Helsingør, Denmark.

Fine, C. H. (1998). *Clockspeed: Winning Industry Control in the Age of Temporary Advantage*. Perseus Books.

Gosling, J., & Naim, M. M. (2009). Engineer-to-order supply chain management: A literature review and research agenda. *International Journal of Production Economics*, *122*(2), 741-754.

Green, S. D. (1999). The missing arguments of lean construction. *Construction management and economics*, *17*(2), 133-137.

Gummesson, E. (2000). *Qualitative methods in management research*. SAGE Publications, Inc.

Hvam, L., Mortensen, N. H., & Riis, J. (2008). *Product Customization*. Springer Science & Business Media.

Jansson, G. (2013). *Platforms in Industrialised House-Building* [Doctoral Dissertation, Luleå tekniska universitet].

Jansson, G., Lundkvist, R., & Olofsson, T. (2015). The role of experience feedback channels in the continuous development of house-building platforms. *Construction Innovation*.

Jensen, P., Larsson, J., Simonsson, P., & Olofsson, T. (2013). *Improving Buildability with Platforms and Configurators* Annual Conference of the International Group for Lean Construction, Fortaleza, Brazil.

Johnsson, H. (2011, 2011). *The building system as a strategic asset in industrialised construction* Proceedings of the 6th Nordic Conference on Construction Management and Organisation: Shaping the Construction/Society Nexus,

Johnsson, H. (2013). Production strategies for pre-engineering in house-building: exploring product development platforms. *Construction management and economics*, *31*(9), 941-958.

Jonsson, H., & Rudberg, M. (2014). Classification of production systems for industrialized building: a production strategy perspective. *Construction management and economics, 32*(1-2), 53-69.

Knotten, V., Svalestuen, F., Hansen, G. K., & Lædre, O. (2015). Design Management in the Building Process - A Review of Current Literature. *Procedia economics and finance, 21*, 120-127.

Koskela, L. (1997). Lean production in construction. In L. Alarcón (Ed.), *Lean construction* (pp. 1-9). Taylor and Francis.

Koskela, L. (2003). Is structural change the primary solution to the problems of construction? *Building Research & Information, 31*(2), 85-96.

Koskela, L., Howell, G., Ballard, G., & Tommelein, I. (2002). The foundations of lean construction. *Design and construction: Building in value*, *291*, 211-226.

Lennartsson, M., & Björnfot, A. (2010). Step-By-Step Modularity: a roadmap for building service development. *Lean Construction Journal*, *2010*(1), 17-29.

Lennartsson, M., & Elgh, F. (2018). *Exploring Product Development in Industrialized Housing to Facilitate a Platform Strategy* Proceedings of 26th Annual Conference of the International Group for Lean Construction, 18-20 July 2018, Chennai, India.

Lessing, J. (2006). *Industrialised House-Building: Concept and Processes* [Licentiate Thesis, Lund University]. Sweden.

Lessing, J. (2015). *Industrialised House-Building - Conceptual orientation and strategic perspectives* [Doctoral Dissertation, Lund University]. Sweden.

Lessing, J., & Stehn, L. (2019). Industrialised house building: Concepts and its application in Sweden. In *Offsite Production and Manufacturing for Innovative Construction* (pp. 86-110). Routledge.

Lidelöw, H., Jansson, G., & Viklund, E. (2015). *Design Breakdown in Industrialized Construction: Supporting Lean Manufacturing* Modular and offsite construction (MOC) summit proceedings,

Miles, M. B., & Huberman, A. M. (1984). Qualitative data analysis: A sourcebook of new methods. In *Qualitative data analysis: a sourcebook of new methods* (pp. 263-263). Sage Publications.

Miller, T. D., & Elgard, P. (1998). Defining modules, modularity and modularization. Proceedings of the 13th IPS research seminar, Aalborg University, Fuglsoe.

Peltokorpi, A., Olivieri, H., Granja, A. D., & Seppänen, O. (2018). Categorizing modularization strategies to achieve various objectives of building investments. *Construction management and economics*, *36*(1), 32-48.

Rampersad, H. K. (1996). Integrated and assembly oriented product design. *Integrated Manufacturing Systems*, *7*(6), 5-15.

Robertson, D., & Ulrich, K. (1998). Planning for product platforms. *Sloan management review*, *39*(4), 19-31.

Rocha, C. G. d., & Koskela, L. (2020). Why Is Product Modularity Underdeveloped in Construction? Proceedings of 28th Annual Conference of the International Group for Lean Construction (IGLC), Berkeley, California, USA.

Sibenik, G., Sreckovic, M., & Radu, A. (2022). Modular process patterns in the design phase. *Proceedings of the Institution of Civil Engineers - Smart Infrastructure and Construction*, *175*(4), 141-151.

Simpson, T. W. (2004). Product platform design and customization: Status and promise. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, *18*(1), 3-20.

Smith, R. E. (2010). *Prefab architecture: A guide to modular design and construction*. John Wiley & Sons.

Thuesen, C., & Hvam, L. (2011). Efficient on-site construction: learning points from a German platform for housing. *Construction Innovation*, *11*(3), 338-355.

Ulrich, K. (1995). The Role of Product Architecture in the Manufacturing Firm. *Research Policy*, *24*(3), 419-440.

Womack, J. P., & Jones, D. T. (1997). Lean Thinking—Banish Waste and Create Wealth in your Corporation. *Journal of the Operational Research Society*, *48*(11), 1148-1148.